The Morphology and Life History of the Finescale Dace, *Pfrille neogaea*, in Itasca State Park, Minnesota.

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ABSTRACT

The distribution of the finescale dace, *Pfrille neogaea*, was found to include the Red River, Rainy River, Lake Superior, and Mississippi River drainages in Minnesota. Its presence in the St. Croix river basin was established. Morphological studies were based on collections totaling 650 specimens taken from a beaver pond located one half mile west of the headwaters of the Mississippi River in Itasca Park. These specimens were collected during the period June 1967 through May 1971. Selected measurements and meristic characters were analyzed for intra-population variation.

Males were found to attain much brighter breeding coloration and had significantly larger pectoral, pelvic, and anal fins than did the females. Only males acquired breeding tubercles. The ratios of the tail length and caudal peduncle depth to the standard length were significantly larger for the males.

The ratios of five selected head proportions varied with the size of the specimens. The snout and upper jaw lengths increased faster than the standard length; the orbit length increased at a slower rate than did the standard length. The ratios snout to orbit length and snout

to upper jaw length increased with an increase in specimen size. The intestine length also increased at a faster rate than did the total length. Despite this allometric growth, the ratios of the snout to upper jaw length and of the intestine length to standard length were found to be of taxonomic value, since these ratios were always less than one. These same values in the genus Chrosomus are greater than one.

Cyclic changes in the gonosomatic index of both sexes indicated that only a single breeding period, in late April and early May, occurred each year. Males did not defend territories, but did vigorously pursue females which departed from the main school of fish. The large pectoral fin of the male was used to hold the female against some object during spawning. Egg deposition took place in depressions under submerged logs or debris. The fecundity of the females was found to increase linearly with the standard length. The maximum number of eggs found in a large female prior to spawning was 3,060. Males averaged slightly larger than females after one year's growth, but females became significantly larger than males after age three.

The major food items of adults were fingernail clams and snails, although aquatic insects were also eaten. Small fish depended primarily on crustaceans and small insect larvae. Although plant material occurred in up 20 percent of the fish in some collections, none of this material appeared to be digested.

Hybrids of Pfrille neogaea with Chrosomus eos have been taken from four locations in eastern Minnesota. All of these were female specimens. Live hybrids collected in May bore bright red pigmentation, which is a male characteristic in the parental species. No hybrid individuals were taken from the population studied in Itasca Park. In this area, Chrosomus eos was found to spawn several weeks later than Pfrille, which resulted in reproductive isolation.

Although some workers have included the finescale dace in the genera Chrosomus and Phoxinus, the evidence gathered in this investigation indicates that this fish is best maintained in the genus Pfrille Jordan 1924.

INTRODUCTION

Although first described more than 100 years ago by Edward Drinker Cope (1869), *Pfrille neogaea*, the finescale dace, has never been the subject of a detailed life history study. Much of the basic ecology of this fish (Osteichthyes:Cyprinidae) is unknown despite its wide distribution throughout Canada and the northern part of the United States (Eddy, 1969:83). Published accounts of the regional fish faunas stress that the finescale dace is rare and restricted to small boggy creeks, ponds and lakes.

The basic biology of *Pfrille* is poorly understood principally due to the difficulty involved in sampling bog habitats. The usual minnow sampling procedure involves seining sections of streams close to road access. This technique is not very successful for obtaining *P. neogaea*. The soft-bottomed, snag-filled bogs usually preclude the use of a seine. These dace are most readily taken by the use of fish traps placed in carefully selected locations.

Even when it is collected, *P. neogaea* is often overlooked because of its strong resemblance to the much more common northern redbelly dace, *Chrosomus eos* Cope, which is usually found in the same habitat. Many collections of *Chrosomus eos* in the University of Minnesota museum contained one or more misidentified specimens of *Pfrille neogaea*.

The finescale dace is also the subject of some confusing nomenclature, although perhaps this is not too surprising in light of the scanty information available about it.

Except for the short morphological descriptions and notes on distribution which appear in keys to the regional fish faunas, little information about *P. neogaea* has been published. Brett (1944) and Tyler (1966) studied the comparative temperature tolerances of *P. neogaea* and *C. eos*; New (1962) and P. Legendre (1970) were interested in the occurrence of hybrids between these species. For such comparative studies to have significance, knowledge of the general biology of the individual species concerned is essential.

To date, much more data are needed concerning the basic areas of distribution, taxonomy, morphology, life history, and ecology of *Pfrille neogaea*; the main objective of this study has been to supply some of this information.

TAXONOMY

Samuel Rafinesque first used the name Chrosomus (1820:101) when he described Chrosomus erythrogaster, or what he called the Kentucky Red Belly, from a specimen taken from the Kentucky River. He placed his new fish in a subgenus of Luxilus.

Edward Drinker Cope (1862:523), on the basis of specimens from Meshoppen Creek, Sesquehanna County, Pennsylvania originated the name Chrosomus eos. Included in his specific description were four distinguishing "peculiarities" which separated C. eos from C. erythrogaster. In 1864 Cope again listed a comparison of C. eos and C. erythrogaster (p.281), this time from specimens taken from streams flowing into Lake Erie at New Hudson, Livingston County, Michigan. Cope subsequently thought that these fish represented a new species, not C. eos, and in 1869 (p.374-375), he named this species Phoxinus neogaeus. This name was based upon the resemblance he noted between these fish and Phoxinus laevis, the common European minnow. (The genus Phoxinus was another new name originated by Rafinesque in 1820, p. 45.) That same year, Cope (1869a) also described Chrosomus oreas from specimens taken in Virginia.

Albert Gunther (1880:599) listed Leuciscus neogaeus as one of the North American examples of the genus meaning "whitefish" which was originated by Cuvier in 1817. According to Gunther, the small fish of the genus

Leuciscus were called "minnows", the larger ones called "shiners" or "dace". *Leuciscus neogaeus* was said to resemble the European species *L. phoxinus*, but differed in having an incomplete lateral line. Barton Evermann (1893) and Evermann and Cox (1896) used the designation *Leuciscus neogaeus* in their reports of the Missouri River fauna; other authors, such as Jordan and Gilbert (1882:243) and William Kendall (1908:26) continued to use Cope's original *Phoxinus neogaeus*.

David S. Jordan (1924:71) created the new genus *Pfrille*, the type of which was *Phoxinus neogaeus* Cope. Jordan had this to say about his new genus:

> "This group, based on a single American species, is very close to the European *Phoxinus* Rafinesque (*Cyprinus phoxinus* L.), differing in the larger mouth, the maxillary reaching to opposite the front of the orbit, and in the very short lateral line which does not reach the ventrals. *Pfrille* is the German name of *Phoxinus phoxinus*."

This change by Jordan was generally accepted, and the genus of the finescale was published as *Pfrille* by many workers (Hubbs, 1926; Hubbs and Brown, 1929; Greeley and Greene, 1931; Greeley and Bishop, 1931,1933; Greeley, 1934; Greene, 1935; Hubbs and Cooper, 1936; Churchill and Over, 1938; Bailey and Oliver, 1939; Dymond and Scott, 1941; Lindeborg, 1941; Johnson, 1942; Eddy, 1943; Hinks, 1943; Radforth, 1944; Brett, 1944; Bangham and Venard, 1946; Wynne-Edwards, 1952; Scott, 1954; Dobie and Meehan, 1956; Scot, 1957; Carl, Clemens, and Lindsey, 1959; Scott and Crossman, 1959; and most recently by McPail and Lindsey, 1970).

Hubbs and Brown (1929) were the first to report the occurrence of hybrids between Chrosomus and Pfrille; these were found in Ontario, Michigan, and New York. They also noticed the great similarity of the two genera. Special mention was given to the similar triangular areas of breeding tubercles anterior to the pectoral fins in both species, a feature attributed only to those two genera. They stated that Chrosomus appeared to be an herbivorous modification of Pfrille, just as Hybognathus appeared to be a herbivorous modification of Notropis. (This is a clarification of a statement appearing in Hubbs, 1926:47). Only the authors' uncertainty about the fertility of the hybrids apparently prevented them from combining Pfrille and Chrosomus at that date.

According to McPhailand Lindsey (1970:252), it was R. Bailey who proposed lumping the two genera in 1951; this suggestion has never been published. V. Legendre (1954) appears to have been the first published account of this change. On page seven he listed Pfrille with Chrosomus, and on page 17 he listed the finescale dace as Chrosomus neogaeus (Cope). The following authors have chosen to call the finescale dace Chrosomus neogaeus in their works: Taylor, 1954; Hubbs, 1955; Underhill, 1957; Eddy, 1957; Hubbs and Lagler, 1958; Bailey, 1960; Nordlie, Underhill, and Eddy, 1961; Eddy and Hodson, 1961; New, 1962; McPhail, 1963; Eddy, Moyle, and Underhill, 1963; Sherrod, 1963; Moore and Braem, 1965; Underhill and Dobie, 1965; Tyler, 1966; Phillips, 1968;

Underhill and Moyle, 1968; Willock, 1969; Scott and Crossman, 1969; P. Legendre, 1969; Eastman, 1970; and Becker and Johnson, 1970. Thus, without any published account, *Pfrille neogaea* (Cope) became *Chrosomus neogaeus* (Cope), and came into general use.

In his work on the fishes of Russia, Berg (1949: 105) listed *Pfrille* Jordan as a questionable species under *Phoxinus*. Banarescu (1964:336), writing on the fishes of Rumania, went one step further and listed *Chrosomus* Rafinesque together with *Pfrille* Jordan as American species of *Phoxinus*. Excepting this addition, Banarescu (1964) reads as an almost verbatum duplicate of the description for the genus *Phoxinus* found in Berg (1949). Banarescu simply listed this lumping of *Phoxinus*, *Pfrille*, and *Chrosomus*; no documentation was given for this action. In a letter to Gary Phillips at the University of Minnesota in 1968, Reeve Bailey made mention of Banarescu's book (Phillips, 1968:6). Smith-Vaniz (1968:53) apparently was the first American writer to accept this change.

After I read the work of Pierre Legendre (1969), I wrote to him to inquire if he was aware of Banarescu's book. (Legendre had still referred to *Chrosomus neogaeus* in his thesis.) Legendre (pers. comm.) replied that he was not aware of it. In his published article, however, Legendre (1970) changed *Chrosomus* to *Phoxinus*, quoting Banarescu (1964) as his source. In 1970, (p. 70), the American Fisheries Society Committee on Names of

Fishes (Reeve M. Bailey, Chairman) revised Chrosomus to Phoxinus quoting Banarescu (1964) as the source of the revision. Although the stated purpose of this publication is to standardize common names, not scientific names, I feel that in practice it has a strong tendency to dictate scientific names. Unless an author is completely familiar with the taxonomy of a particular species, he usually conforms to the scientific name listed for it in this publication. Two of the most recent treatments on regional fish faunas (Fedoruk, 1971; Brown, 1971) have thus included the finescale dace in the genus Phoxinus.

There is no question about Pfrille being closely related to Chrosomus; the chief differences are that P. neogaea has two rows of pharyngeal teeth and only a single loop in the digestive system. The only comparisons I can find between Pfrille and Phoxinus are Cope (1869) who stated, "This species differs from Ph. laevis (sic) by its scaly ventral and vertebral regions, and much shorter lateral line." and Jordan (1924), which has already been mentioned.

Pfrille is also very similar in distribution, general biology, and morphology to the northern dace, Semotilus margarita, and the lake chub, Couesius plumbeus. The main morphological differences between these fish and Pfrille are that they possess complete lateral lines and maxillary barbels. The presence of barbels in the northern dace is of dubious taxonomic value, since they are often absent. Becker and Johnson (1970) have also reported pronounced barbels on some C. erythrogaster collected in the Blue River, Grant County, Wisconsin. Legendre (1970:1176) presented a case for combining S. margarita in the same genus as Chrosomus, based partially on the occurrence of hybrids between these fish. It seems here that the northern dace is more closely related to Pfrille than to other members of the genus Semotilus.

As pointed out by Hubbs (1943:121), there appear to be no objective criteria for genera. Arbitrary decisions often must be made, but it is bad science to deny that the decisions are arbitrary.

McPhail and Lindsey (1970:252) pointed out that the lumping of Chrosomus and Phoxinus by Banarescu had no documentation, and neither did the lumping of Pfrille and Chrosomus. They therefore followed Jordan (1924) in using Pfrille as the best present status for the fine-scale dace. I agree. Until a revision based on all the involved species is published, P. neogaea is best placed by itself in the genus Pfrille. Chrosomus should be maintained as a separate genus.

DISTRIBUTION

The finescale dace is widely distributed across Canada and the northern portions of the St. Lawrence (Great Lakes), Mississippi, and Missouri River drainages in the United States. Many workers have recorded the regional distribution of Pfrille neogaea. It has been reported from as far north as 67°27' North Latitude, and from as far south as 41° North Latitude in Nebraska. It has not been found in Alaska or in any waters west of the Continental Divide.

In Canada it has been taken from the Northwest Territories, British Columbia, and Alberta; (McPhail and Lindsey, 1970: Clifford et al, 1959; Wynne-Edwards, (1952); from Saskatchewan (Willock, 1969) and Manitoba (Hinks, 1943; Fedoruk, 1971); Ontario (Tyler, 1966; Ryder, Scott, and Crossman, 1964; Brett, 1944; Dymond and Scott, 1941; Lindeborg, 1941; Hubbs and Brown, 1929) from Quebec (P. Legendre, 1970; V. Legendre, 1953) and from New Brunswick (Scott and Crossman, 1959).

In the United States, P. neogaea has been found in Maine and New Hampshire (Kendall, 1908); New York (Greeley and Bishop, 1932, 1933); Michigan, (Cope, 1864; Taylor, 1954; Hubbs and Lagler, 1949 and 1964); Wisconsin (Greene, 1935; Becker and Johnson, 1970; Moore and Braem, 1965); North Dakota (Copes and Tubb, 1966; Evenhuis, 1969); South Dakota, (Evermann, 1893; Evermann and Cox, 1896; Churchill and Over, 1938; Bailey and Allum, 1962);

Nebraska, (Johnson, 1942; Jones, 1963); and Wyoming (Bailey and Allum, 1962). Only hybrids (P. neogaea x C. eos) have been reported from Colorado (Bailey and Allum, 1962) and Montana (Brown, 1971). Figure 1 summarizes the distribution of Pfrille neogaea.

Although specimens of P. neogaea have been collected in Minnesota, (University of Michigan Museum of Zoology #86701, year 1860) prior even to Cope's original description, relatively little was known concerning its distribution in this state until quite recently. Eddy (1960) mentioned that the finescale dace was taken from Brule Lake and other waters in Cook and Lake counties which empty into Lake Superior. Underhill (1957) reported the presence of P. neogaea in both the Lake Superior and Arctic drainages of Minnesota, but not in the Mississippi River drainage. Nordlie, Underhill, and Eddy (1961) first reported the occurrence of P. neogaea in the Mississippi River near its headwaters in northwestern Minnesota (Greene, 1935, had previously found the finescale dace in the Mississippi River drainage of Wisconsin). During this present study, several hundred specimens of Pfrille have been taken from the headwater region of the Mississippi River.

In May, 1970 and again in 1971, I collected specimens of P. neogaea and P. neogaea x C. eos hybrids from Wilbur Brook, which enters into the Mississippi drainage via the St. Croix River. These specimens represent the only known record of neogaea from that drainage. Many

FIGURE 1. Distribution of *Pfrille neogaea* in North America. Closed circles represent localities from which *Pfrille neogaea* specimens have been reported; closed triangles indicate localities from which only *P. neogaea* x *C. eos* hybrids have been reported.

additional specimens were found in the University of Minnesota collections which confirm the presence of *P. neogaea* in the upper Mississippi drainage. Three specimens were taken from the boggy Cedar Creek area of Anoka County in 1942, just 30 miles north of Minneapolis.

Bait dealers in Minnesota near Leech and Mille Lacs Lakes occasionally sell finescale dace under the name "rainbow chub." While most of these minnows are supplied from further north, the dealers state that some of their sources are local. Undoubtedly specimens could be taken from Koochiching, Itasca, Cass and Aitkin Counties if enough sampling was done in the proper localities. Figure 2 represents the distribution of the finescale dace in Minnesota, based upon specimens which I have personally inspected. The Appendix contains a list of those specimens. Figure 3 indicates the counties of Minnesota from which confirmed records of *Pfrille* are known.

Unaware of the latter records, McPhail (1963:135-136) postulated that the disbribution of *Pfrille* could be explained by postglacial dispersal from only the Missouri refugium. Legendre (1970:1176) followed this view.

Aware of the presence of *Pfrille* in the headwaters of the Mississippi River, but not of its presence in the St. Croix River drainage, Eddy et al. (1963:112) suggested that it might have been a recent migrant from the Arctic drainage.

FIGURE 2. Distribution of *Pfrille neogaea* in Minnesota. Closed circles indicate localities from which only pure *P. neogaea* specimens have been collected. Closed triangles represent localities from which *P. neogaea* x *C. eos* hybrids have been examined. The closed square indicates the location of Itasca State Park, where this present study was conducted.

In view of the most recent distributional information, it seems most likely that Pfrille's post glacial dispersal pattern was similar to that of C. eos; they migrated north from both the Missouri and Mississippi refugia.

STUDY AREA

Itasca State Park encompasses 32,000 acres in northwestern Minnesota and occupies adjacent portions of Clearwater, Hubbard, and Becker counties. Its location is indicated by the black square in Figure 2. This area was glaciated in late Wisconsin time; the last ice left the Itasca area about 12,000 years ago, leaving a hilly terminal moraine which is now filled with numerous lakes and bogs. The water contained in these bodies forms the source of the Mississippi River.

The areas in Itasca Park from which Pfrille has been collected are shown in Figure 4. This present study was carried out in what I shall call the French Creek Bog area located about three-quarters of a mile west of the point where the Mississippi River drains Lake Itasca (95°10'W, 47°15'N; T143N, R36W, sec. 3 of Clearwater County). French Creek itself is an intermittent stream which drains a boggy lowland area and empties into the western portion of the north arm of Lake Itasca. Beaver activity has greatly modified the original course of the stream and numerous large and small pools presently occupy this area as a result. All specimens were obtained from two adjacent pools of approximately 100 meters in diameter. These pools were formed when beaver dammed the creek where it flowed through a boggy stand of black spruce (Picea mariana). A large beaver lodge was located in the center of the lower pool; starting in 1968, beavers maintained an earthen lip around the edge of the pond. The deepest spot located in the ponds was about four feet. The bottom was composed of very fine silt. Fallen trees, branches, and standing dead spruce trees filled a large portion of the pools. A typical view of the study area at French Creek Bog is pictured in Plate 1.

MATERIALS AND METHODS

Collecting Procedure

Approximately 650 specimens of Pfrille neogaea were collected during the period July 1967 through May 1971. These specimens were taken during all seasons of the year (Table 1).

The vast majority of fish were collected by means of the small minnow traps which were readily available at most fishing tackle shops. These traps were made of wire or plastic. Dimensions were as follows: 24 inches long, 10 inches in diameter at the center, and tapered to about 4 inches at the ends. Fish enter the trap through 1 inch openings on each of the two ends. Because of this design, these traps would not efficiently capture minnow-shaped fish larger than about 150 millimeters, or smaller than about 35 millimeters in length. A fine-mesh dip net was consequently used to collect the young fish less than 30 millimeters; at times, some of the larger specimens were also accidentally taken in this fashion.

Normal collecting procedure was to locate 10 to 12 traps in the beaver ponds at a time; these were placed under fallen trees and branches or some other form of cover. A nylon cord was used to secure the trap to a permanent attachment on the edge of the dam. Three traps were lost early in the study when beaver chewed through cotton cords. All of the traps were checked at least

TABLE 1. Dates and sizes of <u>Pfrille neogaea</u> specimens taken from French Creek Bog.

Standard Length in mm.

DATE	10.0-19.9	20.0-29.9	30.0-39.9	40.0-49.9	50.0-59.9	60.0-69.9	70.0-79.9	80.0-89.9	TOTAL
1967									
January	0	0	1	0	0	2	2	0	5
July	0	0	4	6	4	0	0	0	14
August	0	0	0	4	15	14	8	2	43
Yearly Total	0	0	5	10	19	16	10	2	62
1968									
June	9	1	0	0	0	1	0	0	11
July	0	10	6	1	0	1	1	0	19
August	0	44	20	0	0	1	0	0	65
November	0	0	5	0	0	0	0	0	5
Yearly Total	9	55	31	1	0	3	1	0	100
1969									
April	0	0	15	27	9	1	2	0	54
May	0	0	20	17	3	6	2	0	48
June	0	0	1	5	0	1	1	0	8
September	0	0	0	1	6	2	0	0	9
October	0	0	0	0	2	0	0	0	2
Yearly Total	0	0	36	50	20	10	5	0	121

TABLE 1. (Continued)

DATE	Standard Length in mm. 10.0-19.9	20.0-29.9	30.0-39.9	40.0-49.9	50.0-59.9	60.0-69.9	70.0-79.9	80.0-89.0	TOTAL
1970									
March	0	0	0	12	66	18	5	2	103
April	0	0	0	17	79	16	0	0	112
May	0	0	0	11	22	1	0	0	34
June	0	0	1	1	18	10	1	0	31
August	0	10	1	8	10	2	1	0	32
Yearly Total	0	10	2	49	195	47	7	2	312
1971									
May	0	0	0	0	41	13	1	0	55
TOTAL FOR ALL YEARS	9	65	74	110	275	89	24	4	650

once every 24 hours. Specimens were immediately placed in a solution of formalin. Those fish which were kept alive for aquarium studies were placed in an insulated container and taken to the University of Minnesota where they were released in artificial ponds maintained in the Aquarium Room of the Zoology Department.

Measurements

Measurements of morphological features were taken after the fish had been removed from the formalin and rinsed in fresh water for a period of two days. A Helios dial caliper was used to take all the measurements, which were recorded to the nearest .1 millimeter.

The following body proportion data were obtained for each fish according to the definitions set forth in Hubbs and Lagler (1964): total length, standard length, head length, snout length, upper jaw length, head width, head depth, gape, orbit length, body depth, post-orbital length, caudal peduncle depth, length of depressed dorsal fin, length of depressed anal fin, length of pectoral fin, and length of pelvic fin. In addition, tail length was measured from the posterior margin of the anus to the base of the hypural plate at the mid-lateral body surface. For the purposes of this study, caudal fin length was defined as the total length minus the standard length. Only fishes without damaged fins were included in this determination.

Meristic data, including lateral line scale rows and the number of rays in the dorsal, anal, caudal, pectoral, and pelvic fins, were counted in the manner described by Hubbs and Lagler 1964:19-21

Intestine Length

The entire digestive system from the pharynx to the anus was removed from the specimen. Two 180° loops occur in the digestive tract; these divide the intestine into three parallel straight-line sections. Each of the three sections was measured with a dial caliper and the sum of these was considered the intestine length. All measurements were taken with the intestine placed in a normal relaxed (not stretched) position on a plastic block. The total intestine length was rounded off to the nearest millimeter.

Pharyngeal Teeth

The pharyngeal teeth of minnows are located on the modified fifth gill arch. The arches were carefully removed with forceps and cleaned with fine needles. The pharyngeal teeth formula follows that described in Hubbs and Lagler, 1964:69.

Gonad Weights

The percentage of the body weight attributed to the gonads was determined by the following procedure. First, the fish was removed from the formalin solution and rinsed in fresh water for two days. The excess water was then lightly shaken from the fish and the entire specimen was placed in an empty shell vial. The vial was sealed with a cork and weighed on a Mettler balance; the specimen was then removed and the stoppered vial was again weighed to determine the tare weight. The advantage to this procedure was that the sealed vial prevented any weight change due to evaporation of the fluid from the tissue. This method also allowed any excess water to drain from the fish to the bottom of the vial during the weighing process. In this way, each specimen was drained to a uniform degree.

After the total weight of each fish was determined, the gonads were removed and placed in 1 dram shell vials. The cork-stoppered vials were weighed on the Mettler balance, then weighed again after the gonads were removed. Great care was taken to obtain all the gonadal tissue from the fish, and to exclude any material foreign to the gonads. After the first weighing, all particles of reproductive tissue had to be removed from the vial quickly to prevent excessive evaporation of the drained fluid prior to obtaining the tare weight. Weights for both the entire fish and the gonads were recorded to the nearest milligram.

Egg Counts

The ovaries were removed from the fish and teased apart under a dissecting microscope. Potential fecundity was measured by actual counts of all ova present in the ovaries. No attempt was made to distinguish immature from mature ova, although both kinds were clearly present in many specimens, especially during the breeding season. This method is comparable to that used by Phillips (1969c). The main advantage to counting all eggs is that ovaries do not have to be collected during the breeding season.

After the eggs had been separated from the ovarian tissue and counted, the diameter of the largest ova in each ovary were measured with an ocular micrometer.

Food Items

The entire digestive system was removed from the fish and slit lengthwise with an angular pointed dissecting scissors. The contents of the entire gut were then washed and teased into a small watch glass. Since I was primarily interested in simply identifying the main food organisms, categories were set up which seemed to best describe the different types of food items. Only the number of each category of food items was recorded for each fish. No attempt was made to do a gravimetric or volumetric analysis, since I felt the occurrence method (described by Hynes, 1950) was best suited to the specimens, which had already been collected. The various food organisms were identified under a variable power dissecting microscope. Since the pharyngeal teeth of cyprinids tear many food items into fragments which are difficult to identify and enumerate, I would often have to estimate the numbers of a certain item and relegate others to the category "unidentified animal material."

Age Determination

The age of fishes used in this study was determined from scales, opercular bones, and from length frequency distributions. See Tesch (1968) for a summary of these methods. The scales of _Pfrille neogaea_ closely resemble those of _Phoxinus phoxinus_, as diagrammed by Frost (1943: 146). Frost found that many scales of _Phoxinus_ were unsuitable for age determination due to the rather uniform growth of the circuli. The best results were obtained from scales removed from the caudal peduncle region.

True to its name, finescale dace have very small scales (25 scales from a female _P. neogaea_ 68mm in standard length had a mean diameter of 1.1mm). I found that it was very difficult to see the annuli, since most _P. neogaea_ scales demonstrated circuli of rather uniform appearance. It did not seem to make any difference if the scales were removed from different areas on the body. As a result, many scales were examined from each fish before I was satisfied as to the age estimate.

In cases of doubt, the right opercular bone was removed from the specimen and all the covering tissue scraped off using a scalpel. When viewed under the dissecting microscope, the annular growth marks were easier to see on the much larger opercular bones than they were on the scales.

The ages as determined from scales and opercular bones were compared to length frequency distributions with favorable results. If there was any uncertainty concerning the age of a particular specimen, no age data from it were included in the results.

Field Observations

Prior to setting or checking minnow traps in the French Creek beaver ponds, I walked around on the raised dams at the pond's edge to observe any fish in the water. Eyeglasses with polarized lenses helped to cut down on the reflected glare from the water surface, allowing good visibility to the bottom of the pond. I found that 7x35 binoculars were very helpful in observing fish that were more than six feet distant. All observations were immediately recorded in a notebook.

MORPHOLOGY AND VARIATION

Pfrille neogaea is distinguished from closely related minnows by the following combination of features: very small scales (more than 80 in the lateral line scale row); a single mid-lateral dark band; a large terminal mouth, lacking barbels; a short, incomplete lateral line; a short intestine without loops; pharyngeal tooth formula 2,5 - 4,2. These characteristics are well-known and are used consistently for purposes of identification (Hubbs and Lagler, 1964:70; Eddy, 1969: 83; McPhail and Lindsey, 1970:251). Much less has been published concerning the amount of morphological variation found in this species.

The most useful information to date has been that of New (1962), who included data on morphological variation in his comparison of *P. neogaea* with *C. eos* and *P. neogaea* x *C. eos* hybrids. New's *P. neogaea* data were based on 92 specimens, 54 of which originated in Michigan and South Dakota (made available by the University of Michigan), while the rest apparently represented specimens in the Cornell University collections, origin uncertain but probably New York. His data were based on specimens of diverse backgrounds, and thus contained an unknown source of variability due to differences among the collections.

Pierre Legendre (1970a) in another study of *P. neogaea* x *C. eos* hybrids, based his reference data of *P.*

neogaea on 28 specimens taken from two locations in Ontario. The data compiled from those specimens was not provided in raw form, but as a computer derived discriminant function which combined all the data into a single component. As a result, comparison of Legendre's data with any other morphological information is not possible unless it also was gathered and analyzed according to the exact procedure he outlined.

McPhail and Lindsey (1970:251) reported ranges for many meristic characters, but failed to state anything about the specimens involved, including the sample size.

My own study of the morphology of this species included a large number of specimens taken from a single natural population (French Creek Bog). It became evident as this material was analyzed that many individual elements had an influence on what could be considered the average morphology. Throughout this discussion on morphology, I have tried to emphasize such sources of variation.

Sexual Variation

Coloration

It is a well known fact that many, if not most, cyprinids demonstrate some form of sexually dimorphic coloration, especially during the breeding season. The general pattern would be for the male to take on brighter colors, usually some shade of red or orange, while the female remains quite drab or "normal." This situation holds true for <u>Pfrille</u> <u>neogaea</u> and all of its closely related species.

Brown, Hammer and Koshinsky (1970:1010-1011) described the breeding coloration of the lake chub, <u>Couesius</u> <u>plumbeus</u> (Agassiz) in Saskatchewan. Males developed bright orange markings at the bases of the pectoral and pelvic fins, and around the operculum; females sometimes developed similar color patterns, but not usually of the same intensity as seen on the males. Langlois (1929:161) described the breeding male northern dace, <u>Margariscus</u> (= <u>Semotilus</u>) <u>margarita</u> <u>nachtriebi</u> Cox. It had a bright reddish band deep down on the sides, while females and immature males appeared dull and plain by contrast. Frost (1943:143) gave the following account of the breeding coloration of the European minnow, <u>Phoxinus</u> <u>phoxinus</u>:

> "In the male the back was a green-black, the sides a metallic emerald green with vertical dark stripes; the ventral surface from the proximal end of the jaw to the caudal fin was an intense scarlet. The head was bronze green; under the throat was matt black and the upper and lower jaws had a touch of scarlet. The paired and anal fins were slightly tinted with scarlet, and on the base of these fins there was a milk-white spot, the edge of the opercula also showing a similar white colouring. When the minnows were swimming, these white spots gave a flecked flutter to the dark mass of fish.
>
> The female had much the same colouring of back and sides as the male, the metallic sheen of the sides perhaps more golden and less green than the male. The red of the ventral surface was not so intensely scarlet as in the male and did not extend the full length of the body, and extended forwards for

> about half the abdominal length. The fins and opercula had the same colouring as in the male."

The genus Chrosomus has long been recognized as one of the most brilliantly colored of our native fishes. Jordan and Gilbert (1882:153-154) stated this fact in their descriptions of C. erythrogaster, C. eos, and C. oreas. The excellent color plate of C. erythrogaster found in Forbes and Richardson (1920) has probably drawn much attention to this species over the years. Smith (1908:10) and Phillips (1968:90) contain detailed descriptions of the breeding colors of C. erythrogaster. Phillips found that only yellow and pink occurred on males prior to the intense scarlet of the breeding season. The red coloration was first manifest above the pectoral fins.

The coloration of C. eos was found by Phillips (1968:92-93) to be somewhat similar to C. erythrogaster, but the scarlet was generally less widely spread over the body, although equally intense. Also noted was the fact that some mature C. eos individuals apparently never developed the scarlet coloration, but maintained a bright yellow color on the ventral body regions throughout the breeding season.

Despite the fact that breeding male Pfrille neogaea somewhat resemble Chrosomus males has been long recognized, the coloration of P. neogaea has never been described in detail. Jordan and Gilbert (1882:243) found "belly and lower fins crimson in spring males; pectorals dusky"; this same description also was given in Jordan and Evermann, 1896:241. Scott (1954:58) found "breeding males usually have a brilliant lemon yellow colour on the sides of the body, head, and lower fins." Dobie and Meehan (1956:108) stated that the bright red sides of P. neogaea, like the pearl dace, retain their brilliance most of the year, but are most beautiful in late winter. According to Carl et al., (1959:116) the lower parts of breeding males were crimson, but yellow just before and after the breeding season. Breeding males were found by McPhail and Lindsey (1970:252) to have a red band beneath the dark lateral stripe, with yellow underparts.

During the present study, breeding P. neogaea were collected from the French Creek beaver ponds in late April and in early May of 1969, 1970, and 1971. In every such collection, three distinct color patterns were found on the adult males.

Approximately 30% of the specimens had bright yellow along the entire lower lateral surface, including the cheeks and operculum. The pectoral, pelvic, anal, and caudal fins were also tinted yellow. The entire ventral surface was pure white (Plate 2A). Phillips (1968:93) described the similar situation for C. eos, in which he found some sexually vigorous males never attained the red color, but remained bright yellow

PLATE 2. Breeding coloration of *Pfrille neogaea* males collected April 29, 1970 at French Creek beaver ponds.

A. Yellow phase

B. Red and yellow phase

C. Red phase

throughout the breeding season.

Approximately 60% of the males displayed bright red and yellow lateral surfaces. In this case (Plate 2B) the red band was located just under the dark lateral stripe and the yellow pigment was found immediately below the red band. The cheeks and operculum were normally yellow, as were the pectoral, pelvic, and anal fin; the caudal fin at times contained red pigment at its base. The ventral surface of the fish again remained creamy white, but occasionally red pigment could be seen on the lateral surface dorsal to the dark lateral stripe.

About 10% of the breeding males contained only red pigmentation, as seen in Plate 2C. The bright red band was located directly below the dark lateral stripe and extended from the edge of the operculum to well onto the caudal fin. Any pigment on the cheeks and operculum proper was of the red type. Again the belly region remained creamy white. No trace of yellow coloration was found on this type specimen; the yellow fins of the other two types of specimens were colorless on this type.

Males collected the morning of March 1, 1970, prior to the breeding season, had sides which were either yellow, red, or a pearly pink. The red color was not as intense as it was during the spawning period. Males collected after May lost much of the intense coloration, but in most cases red, yellow, or pearl was always present to some degree throughout the year.

Immature individuals and females usually lacked any trace of yellow or red pigmentation. Greeley and Greene (1931, Plate 5) included an excellent color plate of a female P. neogaea. During the spawning period, many females continued to lack any special coloration (Plate 3A), but many others did develop a band of light yellow pigmentation under the dark lateral stripe (Plate 3B). Examination of the pigment band with a dissecting microscope revealed that occasional chromatophores containing red pigment were present in such females, but very little red coloration on a female was ever noticeable with the naked eye.

It is interesting to speculate about differences in coloration found on the male fish. All the above color patterns had been described earlier by various individuals, but not from the same breeding population. All appeared to be equally well developed sexually, and size was not a factor in color pattern.

Saphir (1934) showed that the breeding colors of C. erythrogaster were influenced by reproductive cycle hormones. Administration of estrus-producing hormone (yohimbine or prolan) brought about full attainment of breeding colors in 50% of the test specimens. Phillips (loc. cit.), Hinks (1943:49), and Carl et al., (1959: 116) suggest that the yellow phase in male P. neogaea and C. eos anticipates and follows the attainment of the bright crimson colors in the same individual.

PLATE 3. Coloration of *Pfrille neogaea* females from French Creek Bog.

A. April 29, 1970

B. May 10, 1969

If this was the case, one would logically expect that those individuals with the red coloration were at their reproductive peak, while the yellow individuals were either past their peak or had yet to attain it. This did not seem to be the case for the yellow *P. neogaea* I encountered, which gave every indication of equal sexual vigor with the red individuals.

Another suggestion would be that the three color types of breeding males represent distinctly different patterns. It is possible that they may be different phenotypes. All three patterns were quite exact; any individual could be easily placed into the appropriate phase. Live males observed in aquaria, including those captured at the height of the breeding season, were never observed to change their color patterns; i.e. yellow males never took on any red, red males never took on yellow, and yellow and red males retained both colors. Determination of the possible genetic and environmental influences relating to these color patterns was beyond the scope of this study but could perhaps be the basis of a future endeavor.

Structural Dimorphism

Mature male and female specimens collected during 1970 were compared for differences in 22 body proportions and meristic characters. The standard t test of Student (Simpson, Roe, and Lewontin, 1960) was used to determine the presence of significant differences in the mean values for the two sexes. The data summarized by Table 2 indicated no significant differences occurred in the lateral line scale rows or in any of the fin ray counts. Highly significant differences between the sexes ($P<0.01$) were found for the ratios of all the fin lengths to the standard length. The fin lengths of the males were clearly proportionally larger than those of the females.

Fin size has been demonstrated to be sexually dimorphic in many minnows (Koster, 1939:204; Langlois, 1929:161; Murphy, 1943:187; Phillips, 1967:11; Raney, 1940:399; Schwartz, 1958:143; Smith, 1908:11). Phillips (1969a:506) found that the length of the pectoral and pelvic fins and the number of rays in pectoral fins were significantly greater in adult male C. erythrogaster than in females. For the adult male C. eos, he found the length of the pectoral, pelvic, depressed dorsal, and anal fin were significantly greater than for the female.

The sexual differences in P. neogaea with respect to fin size, although most pronounced during the spawning period, are expressed throughout the year. The specimens used for the comparison of fin sizes in Table 2 were collected the night of February 28 - March 1, 1970, well before the onset of the breeding period.

The greatest difference in fin size is that of the pectoral fins; those of the adult males are at all

TABLE 2. Comparisons of selected characters in male and female *Pfrille neogaea* collected from French Creek Bog during 1970.

TABLE 2

Character	Sex	N	Range	Mean	Std. error	t value
Lateral line scale rows	M	150	79 - 92	84.45	0.648	0.87
	F	145	80 - 92	84.97	0.679	
Dorsal fin rays	M	150	8 - 9	8.146	0.041	0.61
	F	145	7 - 9	8.117	0.021	
Anal fin rays	M	150	8 - 9	8.106	0.031	0.69
	F	145	7 - 9	8.082	0.040	
Pectoral fin rays	M	150	13 - 16	14.971	0.087	0.56
	F	145	13 - 16	15.037	0.088	
Pelvic fin rays	M	150	7 - 9	7.987	0.025	0.81
	F	145	7 - 9	8.003	0.027	
Caudal fin rays	M	150	18 - 21	19.053	0.040	0.51
	F	145	17 - 20	19.013	0.042	
Ratio $\frac{\text{Depressed dorsal fin length}}{\text{Standard length}}$	M	38	0.2145 - 0.2480	0.2290	0.0012	13.17**
	F	55	0.1856 - 0.2250	0.2068	0.0011	
Ratio: $\frac{\text{Depressed anal fin length}}{\text{Standard length}}$	M	38	0.1756 - 0.2074	0.1982	0.0011	11.06**
	F	56	0.1642 - 0.2003	0.1814	0.0009	

**Highly significant (P<0.01)

TABLE 2 (Continued)

Character	Sex	N	Range	Mean	Std. error	t value
Ratio: $\frac{\text{Pectoral fin length}}{\text{Standard length}}$	M	38	0.1948 - 0.2344	0.2098	0.0015	23.12**
	F	56	0.1500 - 0.1875	0.1709	0.0009	
Ratio: $\frac{\text{Pelvic fin length}}{\text{Standard length}}$	M	38	0.1515 - 0.1782	0.1627	0.0011	16.90**
	F	56	0.1287 - 0.1535	0.1409	0.0007	
Ratio: $\frac{\text{Caudal fin length}}{\text{Standard length}}$	M	114	0.2102 - 0.2771	0.2437	0.0010	2.90**
	F	103	0.1980 - 0.2730	0.2373	0.0014	

** Highly significant ($P<0.01$)

times noticeably larger than those of the adult females (Plate 4A). The enlargement of male pectoral fins is a common characteristic of the Phoxinus - Chrosomus - Pfrille complex; Frost (1943:143) described the similar condition for the European Phoxinus phoxinus. Probably in no other species is the pectoral fin as greatly modified as in P. neogaea. The data from Table 2 show no overlap at all between the sexes for the ranges of the ratio pectoral fin length/standard length. During the course of this study, several hundred specimens were quickly sexed on the basis of this one character, with completely reliable results.

McPhail et al., (1970:251) have already mentioned the peculiar modification found in this fin. They state:

> "....the first pectoral ray develops a heavy splintlike thickening on its anterior surface extending from the base along about one-quarter of the ray, where it ends abruptly to form a distinct notch on the leading edge of the fin. The upper pectoral fin rays are thickened and the membranes between are swollen."

Plate 4B shows this unusual fin structure, which will be shown to play an important role during the spawning process.

Table 3 lists the comparison of 12 characters taken from 30 males and 30 females collected March 1, 1970. These specimens were adult fish specifically chosen so that the mean standard length was nearly identical for both sexes. This test corresponds to that performed by

PLATE 4. Pectoral fin structure.

A. Comparison of the male pectoral fins (upper specimen) with those of the female.

B. Structure of the male pectoral fins. Note the unusual enlargement (arrow) at the base of the first ray.

TABLE 3. Comparison of 12 characters taken from 30 male and 30 female specimens of *Pfrille neogaea* collected in French Creek Bog during the years 1967-1970.

TABLE 3.

Character	Sex	Range	Mean	Std. error	t value
Standard length	M	50.1-59.6	55.67	0.474	0.382
	F	51.5-59.8	55.89	0.382	
Head length	M	14.5-17.3	15.89	0.130	1.51
	F	15.1-17.8	16.17	0.130	
Head width	M	8.7-11.5	10.006	0.114	0.773
	F	8.9-11.7	10.136	0.122	
Head depth	M	10.0-12.0	10.91	0.086	1.132
	F	9.9-11.7	10.75	0.104	
Snout length	M	4.1- 5.5	4.856	0.064	1.613
	F	4.1- 5.5	5.00	0.061	
Upper jaw length	M	5.0- 5.9	5.483	0.052	2.155*
	F	5.1- 6.1	5.646	0.052	
Orbit diameter	M	3.5- 4.0	3.713	0.026	0.662
	F	3.2- 4.0	3.680	0.041	
Body depth	M	12.5-15.5	13.627	0.154	1.770
	F	13.0-16.1	13.990	0.134	
Post-orbit length	M	7.4-9.4	8.243	0.083	1.893
	F	7.7-9.3	8.453	0.072	
Tail length	M	18.4-22.5	20.900	0.206	3.078**
	F	18.1-21.8	20.026	0.194	
Caudal peduncle depth	M	6.3- 8.1	7.096	0.078	4.146**
	F	6.2- 7.6	6.653	0.071	
Gape width	M	4.2- 5.5	4.786	0.052	1.558
	F	4.4- 5.6	4.886	0.055	

* Significant ($P<0.05$)
**Highly significant ($P<0.01$)

Phillips (1968:53-58) for *C. eos* and *C. erythrogaster*. Table 3 indicates no significant differences occurred for head length, head width, head depth, snout length, orbit length, body depth, post-orbit length, or width of gape. The mouth of the females (upper jaw length) was found to be significantly larger ($P<0.025$) than the males'. The tail length and caudal peduncle depth of the males was significantly ($P<0.01$) larger than in the females.

Breeding Tubercles

During the breeding season, most members of the Cyprinidae characteristically develop rows of small epithelial projections called "pearl organs" or breeding tubercles (Reighard, 1903:531; 1904:211). These secondary sex structures are often found to some degree on both sexes, but are usually much more pronounced on the male. Although they normally persist only throughout the breeding season, the placement, structure, and number of these tubercles is quite constant for a given species, and is thus of considerable interest to taxonomists.

Frost (1943:143) described the breeding tubercles of both male and female *Phoxinus phoxinus* from Lake Windemere. Langlois (1929:161-162) found the pectoral fins of the male pearl dace, *Margariscus margarita*, developed paired rows of small tubercles on the first seven rays; females had none. Brown et al., (1970:1010) stated that both sexes of the lake chub, Couesius plumbeus, developed nuptial tubercles, but that those of the female were restricted to the head region and were not developed to the same extent as those of the males. Smith (1908:11) and Phillips (1968:93-96) described the pearl organs of C. erythrogaster; males possessed small tubercles on their fins and over most of the body, but females had smaller tubercles which were usually restricted to the "shoulders" and back.

The breeding tubercles of Pfrille neogaea have been mentioned several times in the literature, but never in detail. Hubbs (1926:34) stated that "Nuptial tubercles apparently never developed." Upon further investigation, Hubbs and Brown (1929:28) found:

> "....breeding males of Chrosomus erythrogaster develop on the triangular area, before each pectoral fin, very regular comb-like rows of nuptial organs, presenting an arrangement entirely unlike that which we had seen in any other fishes. On obtaining some breeding males of Pfrille neogaeus (sic), we observed the same structure - too definite to indicate anything but a direct relationship."

Koster (1939:205-206) described a similar triangular patch of pearl organs near the pectoral fins of male redside dace, Clinostomus elongatus (Kirtland). He found these tubercles similar to those of Chrosomus and Pfrille, and very close to those of Margariscus. On the basis of such similar structures, he concluded the groups Chrosomus - Pfrille and Margariscus - Clinostomus - Couesius form a closely related series. Additional breeding tubercles were found near the base of the anal fin in P. neogaea by Clifford et al., (1959:116) and McPhail et al., (1970:252).

The breeding males of P. neogaea collected during the present study all exhibited a patch of tubercles at the bases of the pectoral fin and anal fin (Plate 5). I found the organs near the anal fin base of most interest, since they were arranged in a pattern apparently unique to the species. They consisted of about six longitudinal rows of scales, each bearing a single large papilla. Breeding males also bore rows of smaller spine-like tubercles along each ray of the pectoral, pelvic, and anal fins (tubercles on rays of the pelvic fin can be seen in Plate 2A). No other area of the male's body bore tubercles, nor were any pearl organs ever found on a female. In all cases, nuptial organs persisted only through the breeding season; they were never observed during any month other than April or May.

Difference in Size

Female P. neogaea appear to average larger in size than males. To test this difference statistically, the standard lengths of 114 males and 102 females collected during March and April 1970 were compared:

Sex	N	Mean Std. L.	Std. Error	t (214d.f.)
M	114	54.215	0.443	4.78
F	102	58.209	0.730	

The females were thus shown to be significantly larger than the males. The largest female taken had a total length of 103.3mm; the largest male was 90.1mm in length.

Progressive Individual Variation

The morphology of an individual of any species is rarely constant throughout its lifetime. Many changes in body form take place from the time of conception until "old age." Mayr, Linsley, and Usinger (1953:82) refer to this change in structure with development as "progressive individual variation." This type of variation usually confronts the taxonomist in two main forms: age or size variation, and seasonal variation.

Variation with respect to specimen size

Ideally, morphological comparisons between populations would involve specimens of the same size. This often is not feasible with natural populations, where one takes what he can collect. Another way to eliminate size as a factor is to express the measurements as ratios, a procedure widely practiced by fish taxonomists. The use of ratios is based on the assumption that the measured body features all grow at the same rate; if this assumption is true, the ratio of any two features should be a constant, independent of the size of the specimen. If the growth of two body dimensions is allometric, however (they increase at different rates), then the ratio of those parts is not a constant, but varies with the size of the specimen.

During this study, the proportions of five selected head dimensions of P. neogaea were found to change with respect to overall size. Included in this comparison were 350 specimens taken from French Creek Bog during the years 1967-1970. The specimens were divided into seven categories according to their total lengths and the mean values of the head proportions were calculated for each sex within the size intervals. The results of this study were summarized in Table 4. Both the ratios snout/standard length and upper jaw/standard length increased significantly with size; the snout grew faster than the upper jaw, however, as was indicated by the fact that the ratio snout/upper jaw also increased with overall size. The ratio orbit length/standard length decreased significantly with an increase in total specimen length. As to be expected from the previous data, the ratio snout length/orbit length increased rapidly as the overall specimen size increased.

Sexual variation in the head proportions did not occur until specimens reached a total length of 60-69 millimeters (this corresponds to a standard length of about 48 millimeters).

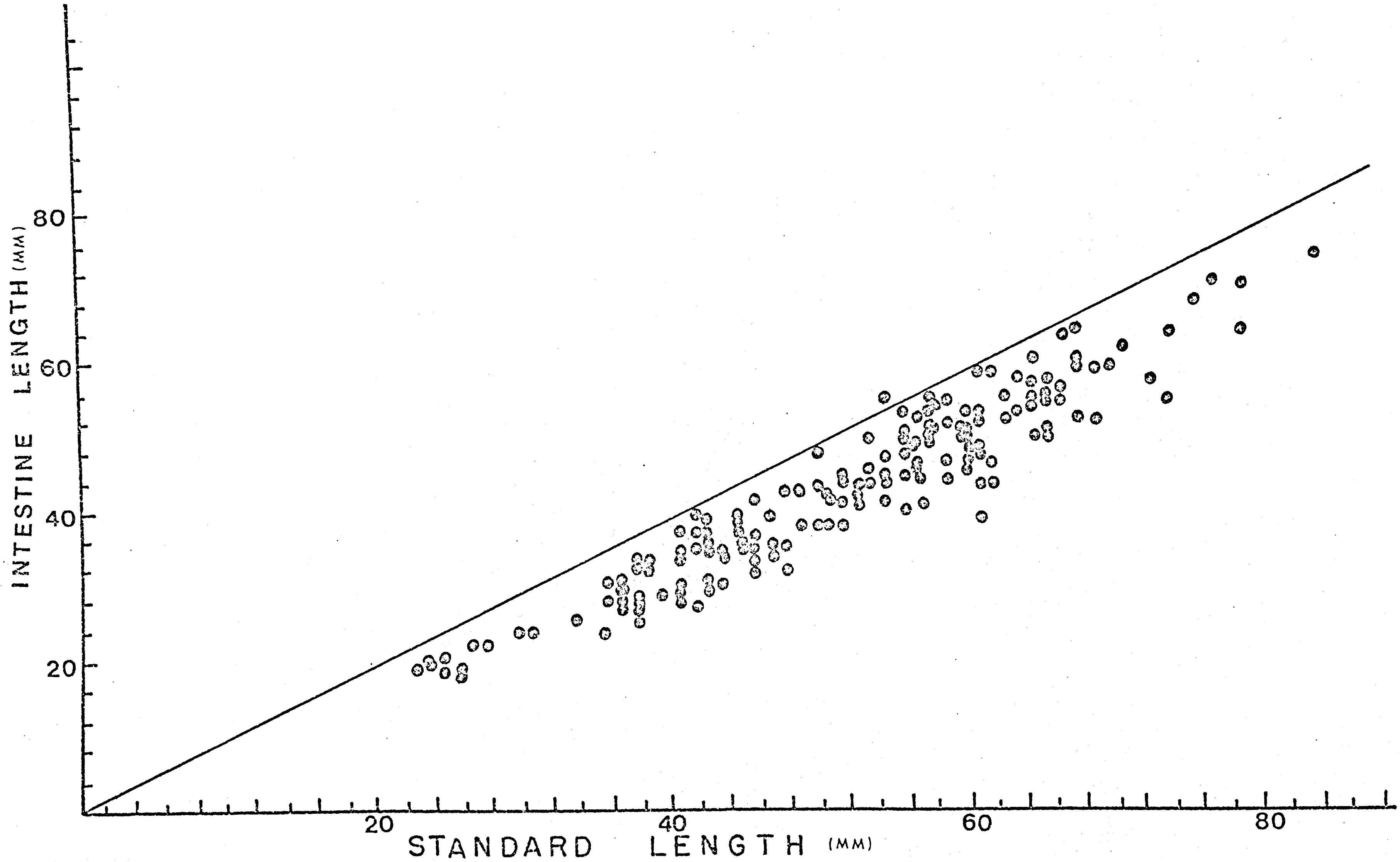
Almost all of the literature on P. neogaea refers to the intestine as being "short," but fails to record any data for this organ. As a means of defining exactly how short the digestive system was in this species, the intestines of 168 fish collected during 1969 and 1970 were measured. Figure 5 shows the comparison of intestine

TABLE 4. Changes in five selected head dimensions of *Pfrille neogaea*. Included in this comparison were 350 specimens collected from French Creek Bog during the years 1967-1970.

TABLE 4.

Total length intervals	Sex	N	Ratio Snout: Std length	Ratio Upper jaw: Std length	Ratio Orbit l.: Std length	Ratio Snout: Upper jaw	Ratio Snout: Orbit l
20.0-29.9	M	8	0.0767±.0015	0.0955±.0013	0.0915±.0021	0.8031±.0016	0.8382±.0104
	F	7	0.0768±.0015	0.0954±.0012	0.0915±.0021	0.8050±.0020	0.8393±.0113
30.0-39.9	M	21	0.0760±.0008	0.0961±.0009	0.0846±.0006	0.7906±.0008	0.8982±.0073
	F	20	0.0759±.0008	0.0960±.0009	0.0844±.0006	0.7912±.0008	0.9104±.0079
40.0-49.9	M	21	0.0819±.0011	0.0970±.0011	0.0793±.0009	0.8440±.0010	1.0321±.0098
	F	21	0.0817±.0011	0.0971±.0011	0.0789±.0009	0.8408±.0009	1.0388±.0091
50.0-59.9	M	23	0.0836±.0009	0.0972±.0008	0.0736±.0007	0.8607±.0008	1.136 ±.0072
	F	14	0.0838±.0017	0.0975±.0012	0.0741±.0007	0.8591±.0016	1.130 ±.0089
60.0-69.9	M	81	0.0851±.0004	0.0975±.0003	0.0685±.0003	0.8736±.0008	1.242 ±.0031
	F	44	0.0862±.0007	0.0985±.0006	0.0684±.0006	0.8745±.0016	1.258 ±.0062
70.0-79.9	M	22	0.0860±.0008	0.0982±.0007	0.0633±.0007	0.8759±.0019	1.357 ±.0120
	F	37	0.0887±.0007	0.0997±.0007	0.0641±.0003	0.8895±.0008	1.382 ±.0100
80.0-89.9	M	6	0.0854±.0024	0.0980±.0025	0.0600±.0015	0.8714±.0020	1.423 ±.0121
	F	15	0.0868±.0011	0.0972±.0012	0.0604±.0011	0.8930±.0012	1.437 ±.0086

FIGURE 5. Scatter diagram showing the relationship of the intestine length to the standard length. The 168 Pfrille neogaea specimens were collected from French Creek Bog during 1969 and 1970. The solid line represents a ratio value of 1:1.


INTESTINE LENGTH (MM)
STANDARD LENGTH (MM)
20
40
60
80
20
40
60
80

length to standard length. In only one specimen was the intestine found to be equal to or larger than the standard length. To check for allometric growth in the intestine length, ten specimens were compared in each of six standard length groups. The data in Table 5 indicated that the intestine increased its length at a faster rate than did the standard length of the fish.

Seasonal Variation

The seasonal variation in 15 body dimensions were compared in 103 specimens taken March 1, 1970 (prior to the spawning period) and April 30, 1970 (during the breeding season). The March collection contained 39 males, 64 females; the April collection had 75 males, 39 females. The March sample proved to be significantly larger with respect to standard length than the April sample. Rather than eliminating all the characters already shown to be influenced by size and sex, they were included on purpose to see what bias they would have in comparing the two "populations." The data from Table 6 indicate no significant differences for the following dimensions: total length/standard length, head length/standard length, head depth/standard length, snout length/standard length, width of gape/standard length, post-orbit length/standard length, tail length/standard length, caudal peduncle depth/standard length, dorsal, anal, and caudal fin rays.

TABLE 5. Comparison of intestine length with standard length.

Ratio of intestine length/standard length

Standard length(mm)	Mean	Std. error	N
20-29.9	0.763:1	0.018	10
30-39.9	0.778:1	0.015	10
40-49.9	0.813:1	0.027	10
50-59.9	0.827:1	0.028	10
60-69.9	0.833:1	0.028	10
70-79.9	0.878:1	0.024	10
all measured specimens, 1969 and 1970	0.829:1*	0.0064	168

*Range 0.638:1 - 1.02:1

TABLE 6. Seasonal variation in 15 selected body dimensions. The March 1, 1970 collection included 39 males, 64 females; the April 30, 1970 collection contained 75 males, 39 females.

TABLE 6.

Character	Date	Mean	Std. error	t value
Standard length	3/ 1/70 4/30/70	57.387 54.910	0.730 0.483	2.885**
Ratio: Total length/Std. length	3/ 1/70 4/30/70	1.2424 1.2343	0.0017 0.0080	0.931
Ratio: Head length/Std. length	3/ 1/70 4/30/70	0.2853 0.2844	0.0010 0.0007	0.634
Ratio: Head depth/Std. length	3/ 1/70 4/30/70	0.1920 0.1897	0.0063 0.0012	1.550
Ratio: Snout length/Std. length	3/ 1/70 4/30/70	0.08796 0.07907	0.0004 0.0065	0.3996
Ratio: Upper jaw length/Std. length	3/ 1/70 4/30/70	0.0989 0.9761	0.0004 0.0003	2.331**
Ratio: Gape width/Std. length	3/ 1/70 4/30/70	0.0804 0.0802	0.0003 0.0003	0.225
Ratio: Orbit diameter/Std. length	3/ 1/70 4/30/70	0.0656 0.0676	0.0005 0.0004	2.844**

**Highly significant (P<0.01)

TABLE 6. (Continued)

Character	Date	Mean	Std. error	t value
Ratio: Body depth/Std. length	3/ 1/70 4/30/70	0.2476 0.2327	0.0008 0.0007	12.488**
Ratio: Post-orbit length/Std. length	3/ 1/70 4/30/70	0.1496 0.1486	0.0006 0.0005	1.206
Ratio: Tail length/Std. length	3/ 1/70 4/30/70	0.3661 0.3671	0.0014 0.0013	0.5344
Ratio: Caudal ped. depth/Std. length	3/ 1/70 4/30/70	0.1214 0.1198	0.0006 0.0007	1.575
Dorsal fin rays	3/ 1/70 4/30/70	8.116 8.052	0.031 0.024	1.611
Anal fin rays	3/ 1/70 4/30/70	8.097 8.104	0.031 0.028	0.170
Caudal fin rays	3/ 1/70 4/30/70	19.019 19.051	0.033 0.040	0.606

**Highly significant (P<0.01)

Found to be significantly different ($P<0.01$) were standard length, upper jaw length/standard length, orbit length/standard length, and body depth/standard length. The ratio orbit length/standard length has already been shown to vary drastically with size (Table 4); this easily explains the difference here. Upper jaw length was already found to vary significantly with both sex (Table 3) and size (Table 4). The one highly significant difference found in Table 6 attributed to seasonal variation was in body depth. Even though no significant difference was recorded earlier for body depth in males and females (Table 3), I thought another comparison between the two sexes in these two collections was in order. The subsequent test (Table 7) revealed that the mean body depth/standard length ratio was nearly identical for the two sexes in each collection. Clearly, the difference found in Table 6 was due to loss of plumpness during the breeding period. Surprising to me was the fact that the change in body depth was proportionally the same for both sexes.

TABLE 7. Body depth changes, 1 March and 30 April 1970

Date	Sex	N	Mean body depth	Std. error	t (101 d.f.)
3/1/70	M	39	0.2474	0.0086	0.132
3/1/70	F	64	0.2472	0.0010	
4/30/70	M	75	0.2317	0.0008	0.421
4/30/70	F	38	0.2362	0.0079	

Annual Variation

Data from collections made 30 April, 1969 and 30 April, 1970 were compared to see how certain body proportions varied over a two-year period. The specimens had all been collected during the breeding season. To eliminate size as a factor, the 36 specimens from 1969 were specifically chosen so that their mean standard length was nearly identical with that of the 1970 specimens. Sex was not a factor, since both collections contained equal numbers of males and females (50% each). Thus, the eight ratios compared did not vary with respect to season, size, or sex; the only variable between the specimens was the year they were collected.

The data from Table 8 indicated that little variation occurred in seven of the eight ratios; only the ratio body depth/standard length differed significantly. This ratio was shown to vary around the spawning period (Table 7). Although the two collections were taken on the identical date, the 1970 specimens apparently began spawning at an earlier time due to yearly differences in temperature. My field records show that the water temperature averaged 10°C. and the air temperature 9°C. during the 30 April, 1969 collecting; during the 30 April, 1970 collecting, the water temperature averaged 16°C. and the air temperature 22°C.

Pharyngeal Teeth

Cope (1869:375) originally described the tooth

TABLE 8. Annual variation in nine selected body proportions. The April 30, 1970 collection contained 57 males, 56 females; the April 30, 1969 collection contained 18 specimens of each sex.

TABLE 8.

Character	Year	N	Mean	Std. error	t value
Standard length	1970	113	54.91	0.48	0.189
	1969	36	54.66	1.73	
Ratio: Total length/Std. length	1970	113	1.234	0.0080	0.193
	1969	36	1.231	0.0026	
Ratio: Head length/Std. length	1970	113	0.2844	0.0007	1.526
	1969	35	0.2816	0.0023	
Ratio: Snout length/Std. length	1970	113	0.0907	0.0065	0.702
	1969	35	0.0824	0.0009	
Ratio: Upper jaw length/Std. length	1970	113	0.0976	0.0003	0.462
	1969	36	0.0979	0.0008	
Ratio: Orbit diameter/Std. length	1970	113	0.0676	0.0004	0.570
	1969	36	0.0671	0.0008	
Ratio: Body depth/Std. length	1970	113	0.2327	0.0007	3.941**
	1969	36	0.2413	0.0030	
Ratio: Post-orbit length/Std. length	1970	113	0.1486	0.0005	0.246
	1969	36	0.1488	0.0014	

**Highly significant ($P<0.01$)

TABLE 8. (Continued)

Character	Year	N	Mean	Std. error	t value
Ratio: Tail length/Std. length	1970	113	0.3671	0.0013	0.996
	1969	36	0.3755	0.0144	
Ratio: Caudal ped. depth/Std. length	1970	113	0.1198	0.0007	0.074
	1969	36	0.1190	0.0012	

formula of _P. neogaea_ as 2,5 - 4,2. Hubbs (1926:33) found the following formulae for seven specimens taken in Maine, Ontario and Michigan:

Left Arch	N	Right Arch	N
1,5	2	1,4	4
2,4	1	2,4	3
2,5	4		

Eastman (1970:193) found that only one arch (left arch = 3,5) varied from the 2,5 - 4,2 formula for 71 specimens of _P. neogaea_ taken in Minnesota. McPhail and Lindsey (1970:251) gave the tooth formula as 2,5 - 4,2 or 2,5 - 5,2.

During this study, 100 pharyngeal arches were examined from the population at French Creek Bog. The arches fit into the following categories:

Left Arch	N	Right Arch	N
1,5	1	4,1	2
2,4	8	4,2	95
2,5	91	5,2	2
		6,2	1

Over 90% of the arches corresponded to the formula 2,5 - 4,2. Only 1% of the left arches and 2% of the right arches contained a single tooth in the minor row. The distinctive left arch bearing the 2,5 tooth formula is shown in Plate 6.

Taxonomic Considerations

A thorough understanding of the morphological variation of a species is important to the taxonomist. This especially true when dealing with closely related forms. In many cases the morphological data obtained from a single species can be quite variable simply due to random bias in the collection with respect to size and sex of the specimens. These factors should be avoided in making taxonomic comparisons unless the variation imparted is completely understood. Several examples of this type of variation were found for P. neogaea. These include: all of the fin lengths (Table 2); upper jaw length, tail length, and caudal peduncle depth (Table 3); the ratios snout length/standard length, upper jaw length/ standard length, orbit length/ standard length, snout length/upper jaw length, and snout length/orbit length (Table 4); intestine length/ standard length (Table 5) and body depth/standard length (Table 6).

In spite of their variation, some of these dimensions can be useful in distinguishing P. neogaea from its closest relatives. In every size class, Phillips (1969a:507) found that the snout of C. erythrogaster and C. eos was larger than the mouth; the data from Table 4 show that for P. neogaea, the snout was always smaller than the mouth (upper jaw length). The intestine length of C. eos and C. erythrogaster is always greater than the standard length; the intestine of P. neogaea is only rarely as long as the standard length (Table 5). These two ratios, together with the pharyngeal tooth formula, should always distinguish *Chrosomus* from *Pfrille*.

Only three body proportions studied did not vary appreciably with size, sex, or season: these were the ratios head length/standard length, post-orbit length/standard length, and head depth/standard length. Not surprisingly, these three values also proved to be very near the mean values of New (1962) for the same characters.

REPRODUCTION

Spawning Behavior

During the course of this study, spawning *Pfrille neogaea* were observed and collected in the French Creek beaver ponds in late April and early May of 1969, 1970, and 1971. Additional observations on breeding behavior were carried out in aquaria at the University of Minnesota during 1970 and 1971. The breeding biology of this minnow had not been described prior to this time (McPhail and Lindsey, 1970:253; New, 1962(1):151).

My field observations for the three spawning seasons were very similar, and can be summarized by the following description.

Breeding behavior always took place in locations of the pond where depressions were covered by fallen logs or a group of branches. The water was usually 1½ to 3 feet deep. Large schools of *P. neogaea* could be seen swimming near the surface of the pond; fish of all sizes were clearly present, including large ripe females and small immature fish born the previous spring. Fish of all sizes seemed to be actively feeding at the surface and all levels beneath the surface. The school would normally stay in the same approximate area as long as I observed them, which at times was more than three hours. The largest males in the school were easily recognizable by their bright colors and large, light-colored pectoral fins. The large males did not defend any territory, did not build any nests, nor did they fight among themselves.

They would usually be positioned lower in the water and toward the back of the school. Males were noticeably more active than females, and while the females usually swam about at a constant pace with few directional changes, the males tended to dart about in small circular patterns.

Although the males were often seen to follow the females closely, it was the female which invariably induced chasing. This occurred when one to three females would suddenly leave the school in the direction of some cover, usually a fallen log. They swam with a definite zig-zag motion which was not seen at any other time. One to many males (usually at least three) would almost immediately begin chasing the zig-zagging females. At this time, the males appeared very aggressive in their attempts to catch the female. The spawning group, now consisting of one or two females and several males, almost always swam into a depression under logs or branches. The substrate was either mud or fine gravel. Because they invariably were hidden from view, I never was able to observe what happened in the cover; presumably egg deposition occurred at this time.

The females would emerge from the cover after approximately 10 to 15 seconds; they would swim normally and rejoin the school. Males tended to linger behind in the cover for a period up to 30 seconds, after which they too rejoined the school. It was not unusual for the same type of spawning behavior to take place several times in a period of thirty minutes.

Finescale dace were easier to collect during the spawning season than during the summer or fall; this is apparently due to the fact that the small minnow traps attracted spawning groups of fish. Females which had been collected under fallen logs in conjunction with brightly colored males were preserved in formalin on several occasions; often these fish would release a number of ripe eggs after they were placed in the jar.

Since the actual spawning act was impossible to observe in the field, several fish in breeding condition were placed in aquaria at the Zoology Building in Minneapolis. On May 9, 1970 the role of the large pectoral fin and anal tubercles of the male was observed. The fish (5 males, 4 females) had been placed in a well-established 20 gallon aquarium containing rocks and live vegetation. Almost immediately, two males began chasing the largest female (in the field, the females initiated the chase). The males would nip at the caudal and anal region of the female as they chased from behind; whenever the female was close to a rock, vegetation or the side of the aquarium, the male would swim alongside the female, placing his large pectoral fin directly behind the pectoral fins of the female. The large, scoop-shaped pectoral fin of the male perfectly fit the body contour of the female and allowed the male to somewhat control the swimming of the pair. With the pectoral fins thus located, the male tried to force the female against some object such as a rock or the side of the aquarium; whenever the male was successful in doing this, it would curl its tail over the tail of the female. In this position, the tubercles above the anal fin of the male were usually adjacent to the vent of the female. The two fish vibrated in this position for several seconds, and then the male released the female. This activity continued for several hours (as long as I was observing them).

Although the release of eggs was not observed during the spawning embrace described, the actual spawning process must be very similar in the field.

On May 7, 1971, seven female and nine male _P. neogaea_ from French Creek Bog were placed in the large fiberglass tank in the Aquarium Room. This tank had a gravel and mud bottom, live vegetation, and two "biological samplers" (loosely interwoven vinyl strands) furnished by the 3M Company. Breeding behavior was noticed almost immediately; especially noticeable at this time was the flickering of the pectoral fins of the males, which appeared to be quite white against the dark background below.

Behavior was similar to that seen in the field, except that spawning took place in and under the vinyl mat instead of under natural obstructions. Several dozen larval minnows were seen in the tank six days later.

The breeding biology of P. neogaea closely resembles that of Couesius plumbeus (Brown et al., 1970); Margariscus margarita (Langlois, 1929); Chrosomus erythrogaster (Smith, 1908); and Chrosomus eos, (Cooper, 1936).

Sex Ratios

Sex ratios were determined for 12 collections of finescale dace. The results are summarized in Table 9. The total sex ratio of all the adult fish in my collections was very close to 1:1. Many of the larger collections taken during the breeding season showed that the males outnumbered the females substantially during this period. This is probably best explained by the tendency for many males to chase a smaller number of females into spawning cover; at times the spawning cover turned out to be one of my minnow traps.

Spawning Season

The spawning season of P. neogaea has been mentioned twice in the literature. Slasteneko (1958: 213) reported "spawning in June-July"; New (1962: 151) stated "breeding males" were collected by seine in Line Pond, Franklin County, New York in August 1955 and June 1958.

In Itasca Park, Minnesota, spawning was observed in late April and early May. Pfrille neogaea must be one of the earliest of northern minnows to breed in the springtime since spawning fish were collected between April 27-30, 1969. Air temperature ranged from -5° to

TABLE 9. Sex ratios of Pfrille neogaea collections.

Date	No. of males	No. of females	Ratio males/females
August 1967*	21	21	1.00:1
April 29, 1969*	15	16	0.937:1
May 13, 1969*	19	20	0.950:1
March 1, 1970*	39	64	0.609:1
April 30, 1970*	75	39	1.923:1
May 8, 1970*	18	16	1.125:1
June 28, 1970*	12	18	0.666:1
August 7, 1970*	1	5	0.200:1
August 16, 1970*	6	8	0.750:1
May 7, 1971*	41	15	2.70:1
May 23, 1971**	26	4	6.50:1
July, 1971***	24	27	0.888:1
Total	297	253	1.17:1

* French Creek Bog, Itasca State Park

** Pickerel Lake, Cook Co.

*** Clarke Lake, Itasca State Park

13°C. during this period, and the water temperature reached as low as 11°C. when spawning behavior was observed; many of the larger lakes in the park region were partially covered with ice.

Ahsan (1966b), in discussing the relationship of the environmental factors to breeding in Couesius plumbeus, considered temperature to be the major factor controlling spermatogenesis. He found evidence, however, that photo-period had a positive effect on sperm production in the terminal phase of maturation. Perhaps this also explains the ability of P. neogaea to spawn in such relatively cold water.

The shallow water found in the beaver ponds was subjected to fairly large fluctuations in water temperatures during this time of year. Water temperatures during the spawning activity observed May 6-8, 1970 ranged from 13-18° Celsius. Perhaps spawning is triggered as a response to the sudden rise and fluctuation in water temperature which takes place following the disappearance of the ice. Fish collected from French Creek Bog May 6, 1971, in water 15°C. were released the following day in water of 24°C. in a large aquarium at the University of Minnesota. They proceeded to spawn vigorously almost immediately.

The breeding cycle of fishes living in temperate climates can often be demonstrated by comparing the ratio gonad weight/total weight for collections taken at different times of the year (Bagenal, 1967, 1968;

Henderson, 1962; Le Cren, 1951; Peters, 1971; Turner, 1919; Williams, 1959). The ratio gonad weight/total weight is often called the maturity index by some authors (Behmer, 1965; Johnson, 1971; Vladykov, 1956); others refer to it as the gonosomatic index (Ashsan, 1966a).

During this study of P. neogaea, the ovaries of 93 females and the testes of 88 males taken at different times of the year were compared to the total weight (Table 10). The seasonal changes in the size of the gonads was essentially similar to that described for Phoxinus (Bullough, 1939), Chrosomus (Phillips, 1968), and Couesius (Ahsan, 1966a). The gonosomatic index of P. neogaea did not appear to vary with the size of the specimen. In order to demonstrate the regularity of the reproductive cycle, the data from Table 10 was incorporated into a graph (Figure 6). It would have been desirable to include samples collected in early April and late May, but no specimens were collected from French Creek Bog during that period. From Figure 6 it is clear that only one spawning period occurred each year and that it was essentially completed before the first of June. Some literature reports indicate that C. eos might spawn twice a year (Cooper, 1936:141; Slastenko, 1958:212).

The highest individual value for the gonosomatic index of P. neogaea was 18.81% for a female collected

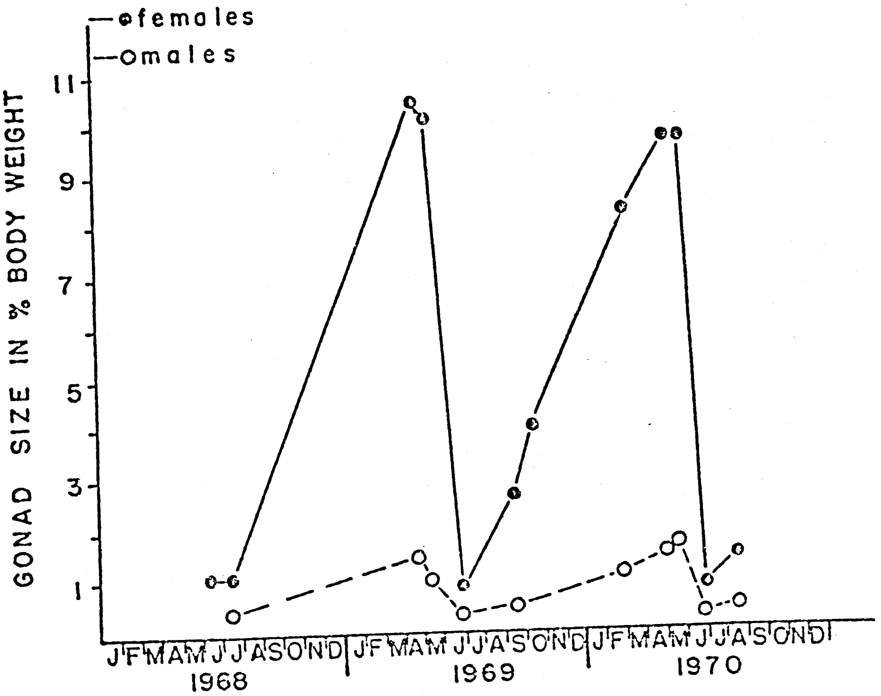
TABLE 10. Seasonal gonosomatic indexes for 93 female and 88 male *Pfrille neogaea* collected from French Creek Bog.

A. Females

Date	N	Mean Gonad Wt./Total Wt.	Std. Error
6/14/68	1	.0130	.0000
7/20/68	1	.0138	.0000
4/30/69	9	.1043	.0078
5/13/69	7	.1001	.0183
6/29/69	4	.0083	.0012
9/28/69	4	.0285	.0043
10/19/69	2	.0347	.0024
3/ 2/70	20	.0802	.0026
4/30/70	20	.0981	.0031
5/ 8/70	8	.0957	.0073
6/28/70	10	.0093	.0003
8/16/70	7	.0161	.0011

B. Males

7/20/68	2	.0036	.0001
4/30/69	9	.0144	.0007
5/13/69	11	.0104	.0007
6/29/69	1	.0037	.0000
9/18/69	5	.0043	.0003
3/ 1/70	20	.0117	.0004
4/30/70	20	.0139	.0004
5/ 8/70	4	.0164	.0000
6/28/70	10	.0030	.0001
8/16/70	6	.0037	.0002



—● females
—○ males
GONAD SIZE IN % BODY WEIGHT
11
9
7
5
3
1
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1968
1969
1970

May 10, 1969. This fish was spawning at the time of capture, and it released many eggs into the jar of formalin. The largest value for the males was 1.68% on May 8, 1970. Phillips (1968:100) reported maximum values of 19.73% and 1.51% for female and male *C. erythrogaster*, while Ahsan (1966a) reported the maximum of 2.1% for male *Couesius plumbeus*.

Fecundity

Several definitions of fish fecundity have been used by different researchers; there have likewise been many ways to determine it. For the purposes of this study, fecundity was defined as the number of ripening eggs found in the female just prior to spawning (Bagenal, 1967:89). Various techniques have been used in counting fish eggs. These include direct counts, automatic egg counters, volumetric and gravimetric estimation (see Bagenal and Braum, 1968 for a summary of these).

In earlier studies, Phillips (1968:111; 1969c:525) found that the fecundity of *C. erythrogaster* in Minnesota ranged from 9,030 to 18,888 (based on 10 large specimens 70.4-81.4 mm in total length) with a mean value of 13,488. The mean fecundity of five *C. eos* from the Mississippi River in Itasca Park was given as 14,969.

Although *P. neogaea* is a larger fish than any of the *Chrosomus* minnows, it proved to be much less fecund. The total number of eggs was counted for each of 20 female finescale dace collected April 29 and 30, 1970 (Table 11A). The largest number of eggs found in a

TABLE 11. Fecundity of female *Pfrille neogaea* collected during March and April, 1970.

A. Females collected April 29 and 30, 1970.

B. Females collected March 1, 1970.

TABLE 11A. Fecundity of females collected April 29 and 30, 1970.

Age Class	Std. length	Total wt.(g)	Ovary wt.(g)	%Ovary wt./Total wt.	# of eggs
II	44.8	2.12	0.135	6.35	784
III	50.0	2.55	0.247	9.68	1,240
III	51.1	3.03	0.367	12.08	1,420
III	54.3	2.92	0.319	10.50	1,630
III	55.0	3.89	0.493	12.66	1,890
III	56.5	3.09	0.297	9.61	2,060
III	57.5	3.38	0.298	8.71	1,410
III	57.6	3.14	0.286	9.08	1,740
III	58.0	3.25	0.297	9.12	1,780
III	58.1	2.86	0.299	10.44	1,840
IV	63.5	4.55	0.537	11.79	2,270
IV	64.5	4.65	0.379	8.14	2,550
IV	65.9	5.08	0.522	10.27	2,780
IV	66.1	4.73	0.371	7.84	800*
IV	66.1	4.83	0.492	10.18	2,800
IV	67.4	5.50	0.521	9.47	2,360
IV	68.0	5.42	0.635	11.00	2,590
V	75.8	8.08	0.744	9.20	2,700
V	76.5	8.81	0.620	7.03	3,060
V	78.9	9.20	1.733	18.82	2,775

*This fish had been spawning at the time of capture; many eggs were probably released already.

TABLE 11B. Fecundity of females collected March 1, 1970.

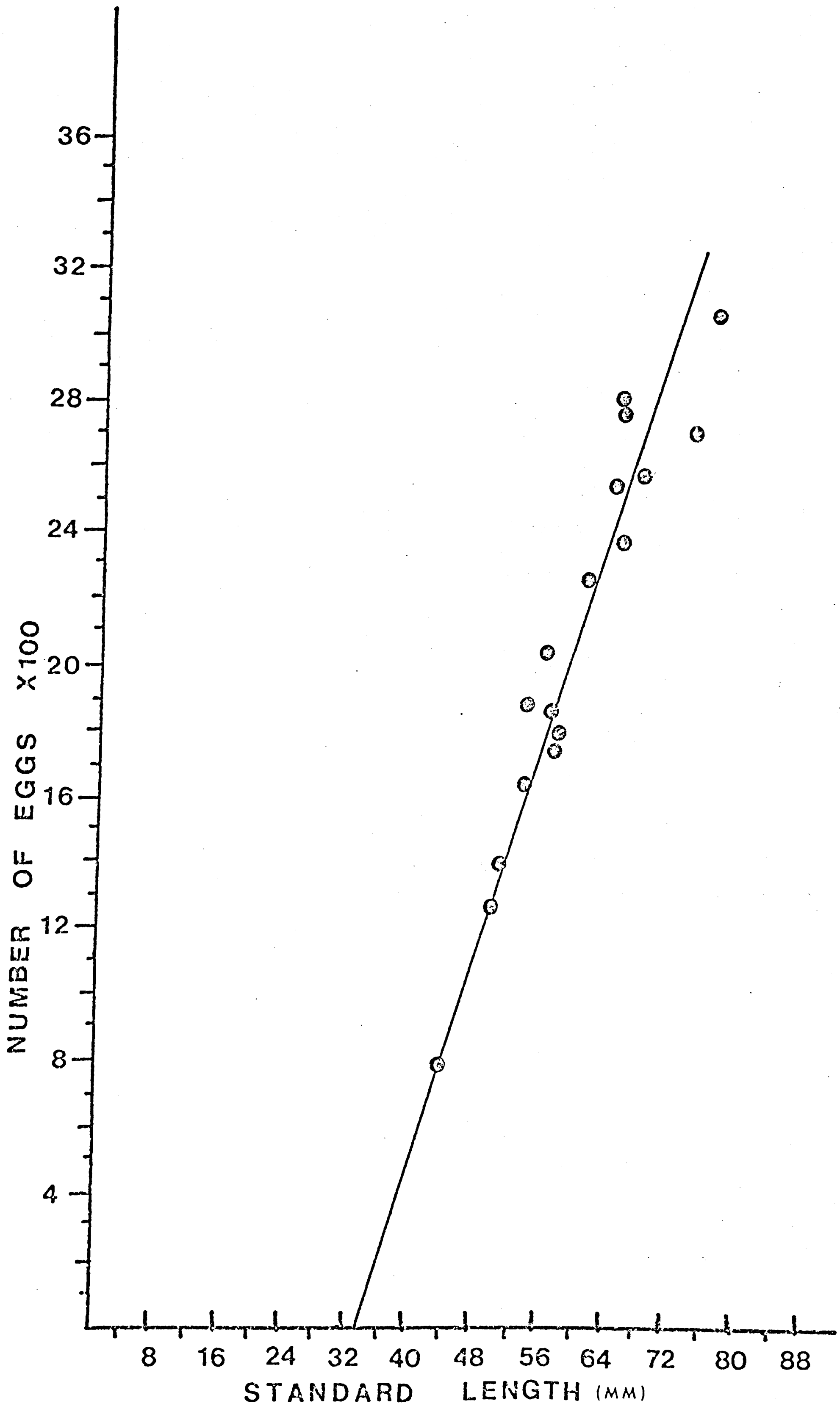
Age Class	Std. length	Total wt.(g)	Ovary wt.(g)	Ovary wt. Total wt.	# of eggs
IV	65.0	5.24	0.460	8.77	3.670
IV	69.0	6.07	0.442	7.27	2,650
IV	70.2	6.91	0.651	9.41	3,480
V	76.3	8.21	0.822	10.00	4,970
VI	82.0	10.61	0.994	8.55	5,850
VI	84.0	10.00	0.729	7.29	3.080

single specimen was 3,060. All of the eggs in the ovaries of the fish in this collection corresponded to the mature or ripe stage (Nikolsky, 1963). The eggs averaged 1.1mm in diameter, with a range of 0.8-1.3mm. At least some of these fish were known to have been spawning at the time of capture. The size and location of the ovaries in one of these fish is shown in Plate 7.

To determine if the relatively low egg counts in the April collection were due to the loss of eggs in previous spawnings, counts were made of the eggs of six large females collected March 1, 1970 (Table 11B). The egg counts were slightly higher for these fish, with a maximum of 5,850 for a female 82mm in standard length. The ovaries of the fish taken March 1, 1970 contained two distinct size classes of eggs. Many eggs were nearly identical in size and appearance (yellow-orange) with those found in late April; these were the mature eggs. In addition, numbers of smaller (0.3mm-0.5mm) eggs were found. These probably represented those eggs, often called recruitment stock, which develop into the mature eggs (Bagenal, 1967:90). Some of the eggs counted in the March sample probably represented atretic eggs which were reabsorbed prior to the maturation stage observed in the late April sample. Wagner and Cooper (1963) reported 72% of the eggs of the creek chubsucker, Erimyzon oblongus, were atretic. This fact may also explain the slightly larger egg counts obtained from the March sample.

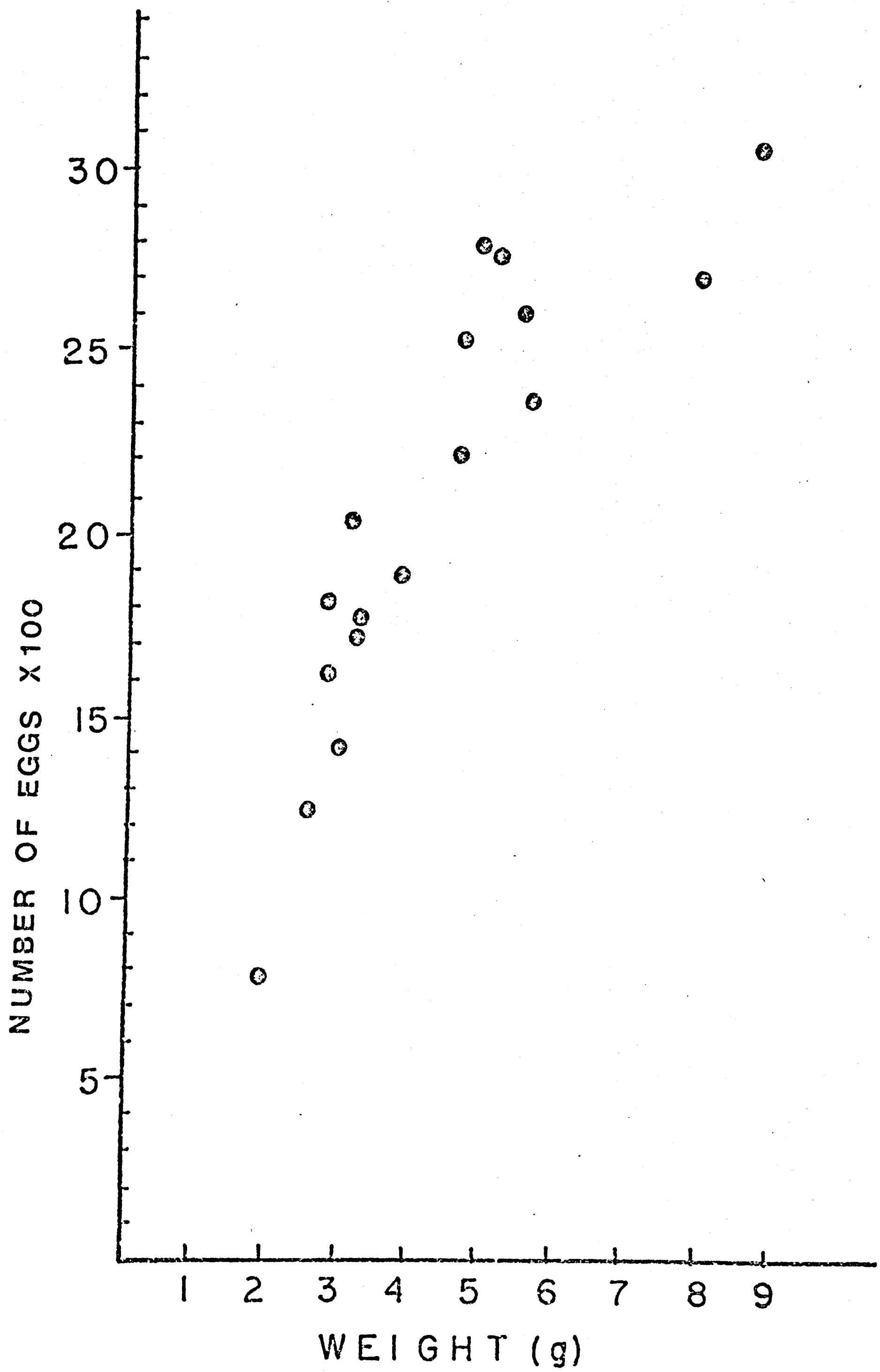
Comparisons were made of fecundity with standard length (Figure 7) and weight (Figure 8). Fecundity appeared to be linearly proportional to the standard length and decreased in relation to an increase in total weight. Apparently the ovaries of older fish produce larger and fewer eggs, and the connective tissue increases disproportionately.

FIGURE 7. Relationship of fecundity to standard length, based on 20 specimens of *Pfrille* collected April 29 and 30, 1970.



36
32
28
24
20
16
12
8
4
NUMBER OF EGGS X100
8
16
24
32
40
48
56
64
72
80
88
STANDARD LENGTH (MM)

FIGURE 8. Relationship of fecundity to total weight, based on 20 specimens of *Pfrille neogaea* collected April 29 and 30, 1970.


30
25
20
15
10
5
NUMBER OF EGGS X100
1
2
3
4
5
6
7
8
9
WEIGHT (g)

AGE AND GROWTH

Early Development

On May 8, 1970 eggs were stripped from a ripe female *P. neogaea* into a petri dish containing a small amount of water. The eggs were released easily, were dark yellow in color, sank quickly, and averaged 1.4mm just prior to fertilization. About 100 eggs, which were non-adhesive and separated, were immediately fertilized by stripping milt from two males directly over the eggs. All three fish had been collected from French Creek Bog the previous day and transported to the Zoology Building in Minneapolis.

Although most of the eggs demonstrated some development, only four succeeded in hatching exactly four days later. This was probably due to the fact that the room temperature of 24°C. was much higher than the normal temperature of the pond at this time of year, and the eggs were undoubtedly crowded. No aeration was provided. The four newly-hatched fish averaged 4.2mm in total length. The larval fish first began to swim for very short periods three days after hatching (Plate 8). They were then released into a well-established aquarium. The first observation of active feeding took place seven days after hatching, when the larvae corresponded to stage 33 of Balinsky (1948:337). At ten days of age the fish ate small particles of dry prepared food from the surface of the water. At 19 days of

PLATE 8. Larvae of *Pfrille neogaea*.

A. 3 days old

B. 4 days old

TABLE 12. Mean standard lengths of *Pfrille neogaea* age groups. Age group 0 was collected with a dip net during 1968; the older age groups were collected during the spawning seasons of 1969, 1970, and 1971. The standard lengths of age groups I to VI were rounded to the nearest millimeter.

TABLE 12.

Age 0

Date	Mean	N	Range
6/23/68	17.8	11	15.4-21.8
7/20/68	25.6	19	20.9-30.4
8/10/68	30.0	44	26.8-35.0
11/23/68	35.3	5	32.2-37.5

Age I

	Females			Males		
Date	Mean	N	Range	Mean	N	Range
4/30/69	38.0	16	34-41	41.0	16	34-43

Age II

	Females			Males		
Date	Mean	N	Range	Mean	N	Range
4/30/69	46.0	9	41-48	48.0	11	41-52
4/30/70	51.0	18	46-56	51.0	25	42-53
Total	49.5	27	41-56	50.0	36	41-53

Age III

	Females			Males		
Date	Mean	N	Range	Mean	N	Range
4/30/69	54.0	9	50-60	65.0	6	55-60
4/30/70	58.0	10	53-60	55.0	27	53-58
5/ 7/71	58.0	5	55-61	57.0	22	55-61
Total	56.5	24	50-61	56.0	55	53-61

TABLE 12 (Continued)

Age IV

	Females			Males		
Date	Mean	N	Range	Mean	N	Range
4/30/69	66.0	3	65-70	61.0	3	60-64
4/30/70	66.0	8	62-70	59.0	12	56-64
5/ 7/71	66.0	2	66	61.0	8	59-63
Total	66.0	13	62-70	60.0	23	56-64

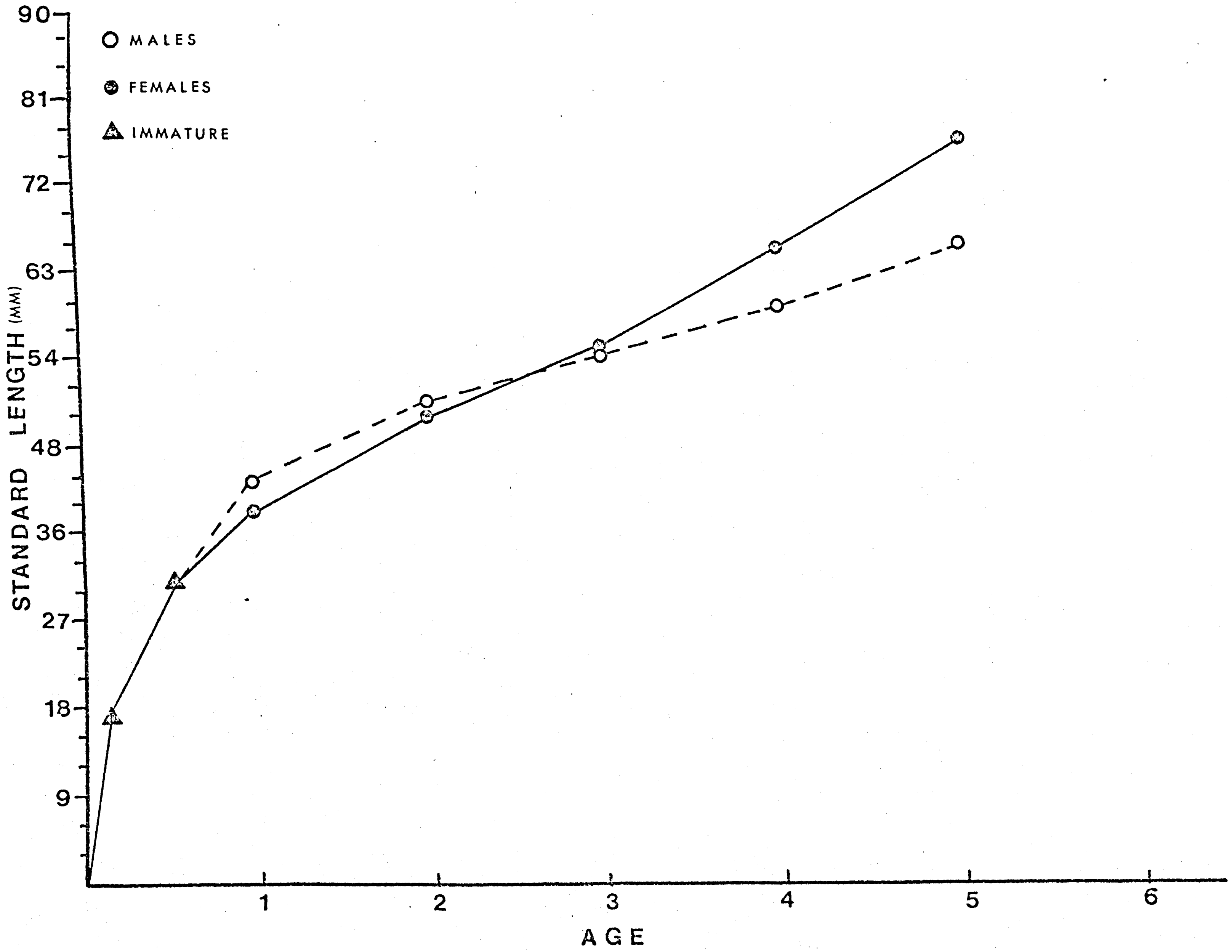
Age V

	Females			Males		
Date	Mean	N	Range	Mean	N	Range
4/30/69	76.0	4	72-80	67.0	1	67
4/30/70	77.0	3	74-48	67.0	3	64-68
Total	76.5	7	72-78	67.0	4	64-68

Age VI

	Females		
Date	Mean	N	Range
3/ 1/70	83.0	2	82-85

FIGURE 9. Growth rates of _Pfrille neogaea_, based the data from Table 12.



90
81
72
63
54
48
36
27
18
9
MALES
FEMALES
IMMATURE
STANDARD LENGTH (MM)
1
2
3
4
5
6
AGE

External sexual differences apparently developed during the first winter, at a standard length of about 38mm. At the end of April, when the fish were approximately one year old, almost all of the males could be distinguished from the females solely on the basis of external characteristics. Complete sexual maturity for both males and females, however, was not attained until the second year.

Population Age Structure

Length frequency distributions were made for the collections taken the night of February 28-March 1, 1970 (Figure 10) and on April 30, 1970 (Figure 11). Since minnow traps were used to take these fish, specimens of age group I were not adequately sampled, and were thus eliminated from the data. Figures 10 and 11 consequently show the distribution of the sexually mature individuals prior to (beginning of March) and during (end of April) the spawning season.

Because the breeding season of these dace is quite short and the growth is very uniform (Figure 9), the year classes were clearly represented by the modal lengths on the diagrams. Assuming that the minnow traps used were not biased with respect to age group I to VI, the collection taken through the ice on March 1, 1970 should have been representative of the population structure prior to spawning. Figure 12 shows the survivorship curve for the fish taken in that collection.

FIGURE 10. Length frequency distribution of male and female *Pfrille neogaea* collected from French Creek Bog March 1, 1970.

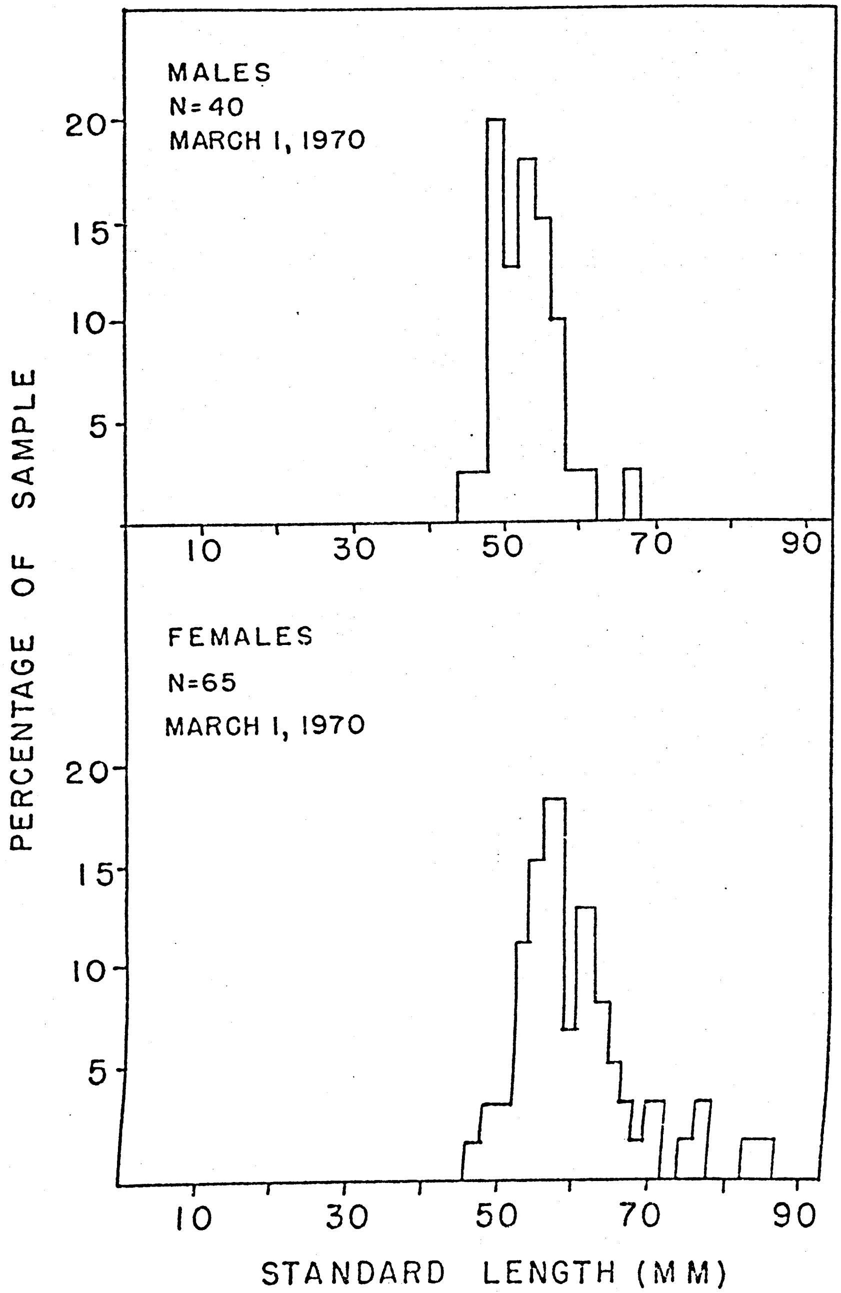

MALES
N=40
MARCH 1, 1970
FEMALES
N=65
MARCH 1, 1970
PERCENTAGE OF SAMPLE
20
15
10
5
10
30
50
70
90
STANDARD LENGTH (MM)

FIGURE 11. Length frequency distribution of male and female *Pfrille neogaea* collected from French Creek Bog April 30, 1970.

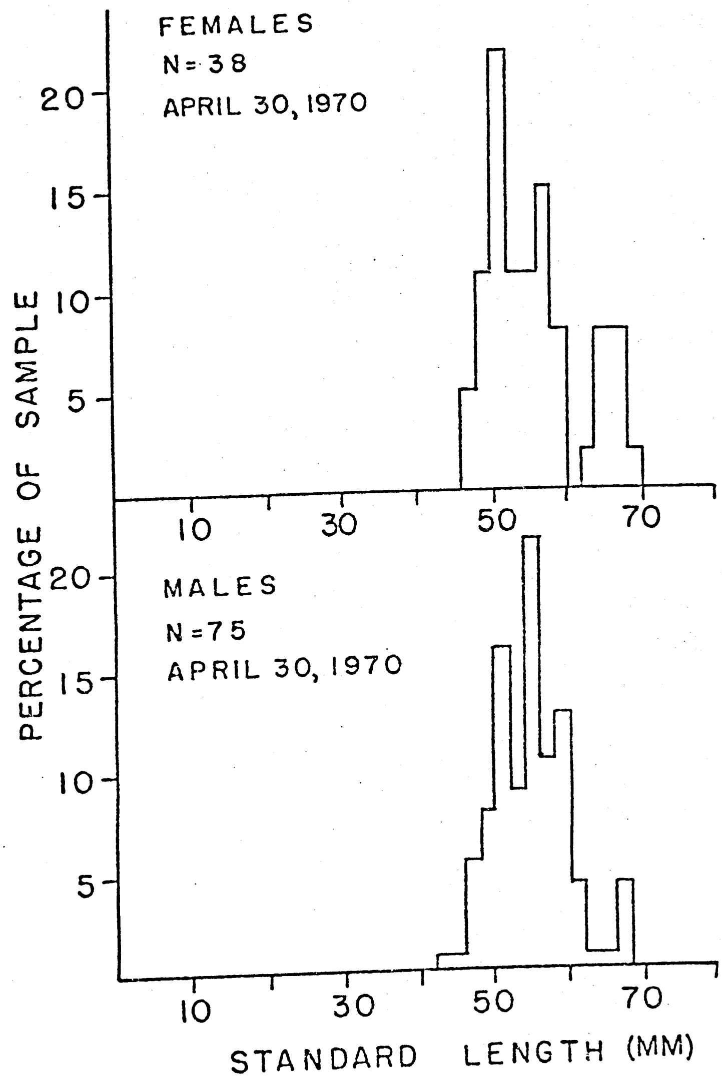
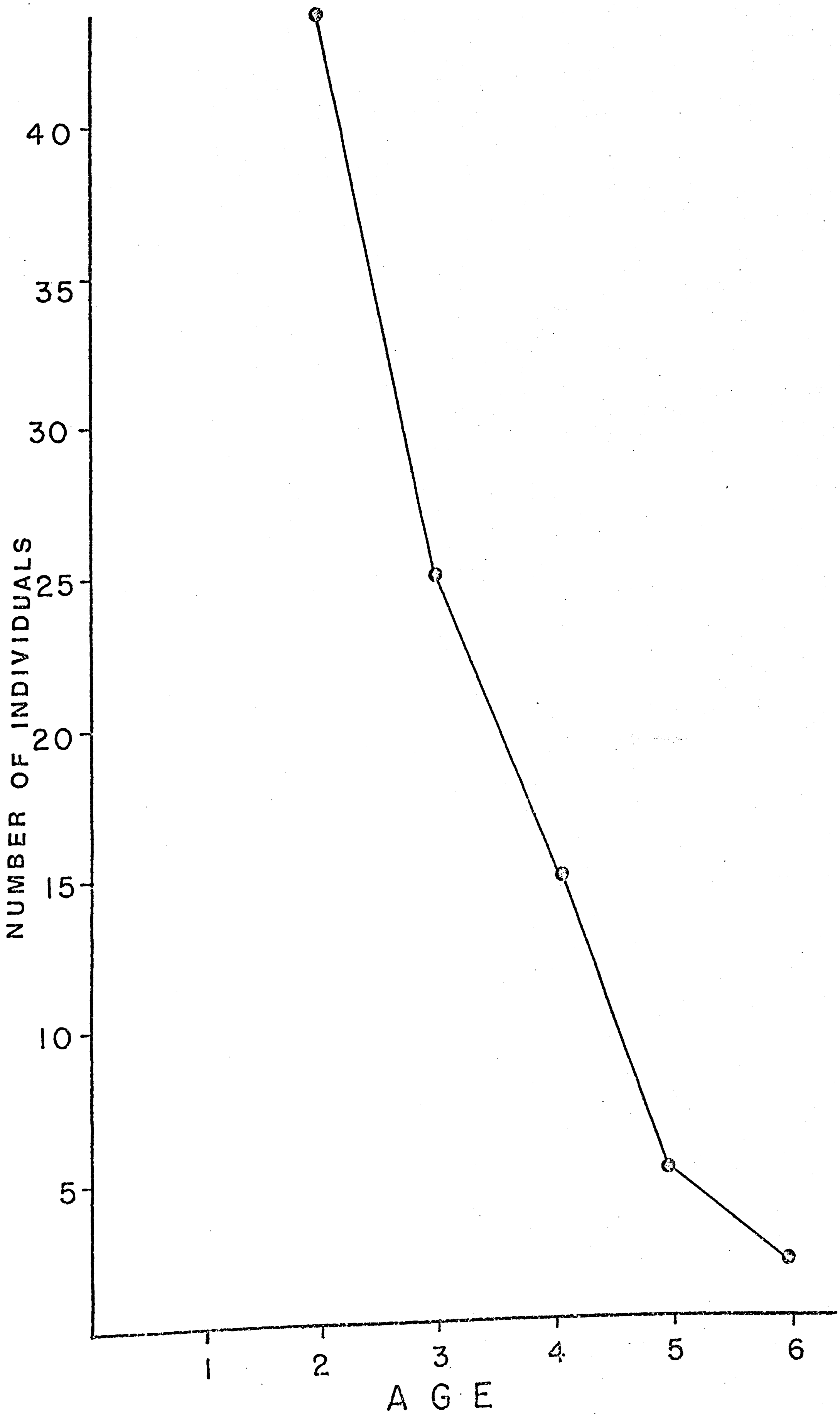

FEMALES
N=38
APRIL 30, 1970
MALES
N=75
APRIL 30, 1970
PERCENTAGE OF SAMPLE
20
15
10
5
10
30
50
70
STANDARD LENGTH (MM)

FIGURE 12. Survivorship rate of *Pfrille neogaea*, based on 103 male and female specimens collected from French Creek Bog March 1, 1970.



40
35
30
25
20
15
10
5
NUMBER OF INDIVIDUALS
1
2
3
4
5
6
AGE

The composition of the spawning population can be seen in Figure 11. The female component of this collection was represented by the same relative age group structure as seen in the earlier pre-spawning collection. The relative recruitment potential based upon the numbers of eggs produced by each year class indicates that females of age group III contributed about 38.5%, age group II about 35%, and age group IV and older, 26.5%. This assumes that each of the eggs are equally viable for all age groups. Observations suggest that the larger females produce slightly larger eggs, which may have a selective advantage over smaller ones. It was also observed that the males on the spawning grounds preferred the largest females.

The males of age group III comprised the dominant group collected during the spawning season, although they were outnumbered by age group II (Figure 10). Age group III also was the dominant male class found during the 1971 spawning season. Apparently the competition among the males for receptive females provided a definite size advantage to the older fish.

FOOD STUDIES

Diet Composition

Very little information concerning the food habits of Pfrille neogaea has been available in the literature. Dobie and Meehan (1956:108) reported the following:

> "The limited food studies conducted indicate that both phytoplankton and higher plants are preferred. In some stomachs, however, nearly half of the food has been insects, and the minnow is known to eat zooplankton and crustaceans to a limited extent."

McPhail and Lindsey (1970:253) stated that dace from three localities in their area (Northwestern Canada) had fed mostly on insects. Hubbs and Cooper (1936:14) included the finescale dace as one of four example species of distinctly carnivorous minnows. They characterized these fish as possessing "large terminal mouths for seizing animals; pointed and hooked pharyngeal teeth, for holding their prey and tearing the flesh, and a very short intestinal tract, which suffices for the rapid digestion and assimilation of animal matter."

The intestinal contents of 348 finescale dace from French Creek Bog were examined during this study. The results are indicated by Table 13 for fish larger than 35mm standard length, and in Table 14 for young specimens less than 35mm. The food of the large specimens did not seem to vary substantially from March through September, with one exception. Crustaceans (Amphipoda and Choncostraca) were encountered in over 10% of the fish examined from the March and April collections, but

TABLE 13. Diet of adult (larger than 35mm) *Pfrille neogaea*, based on the percent of total occurrences in specimens from French Creek Bog.

TABLE 13.

Food Item	% Total Occurrence March 1970 N=52	April 1969 N=54	April 1970 N=54	May 1969 N=47	May 1970 N=32	June 1970 N=27	Aug 1970 N=14	Sept. 1969 N=9
Sphaeriidae	17.0	52.7	29.0	30.5	20.0	33.1	35.6	11.1
Gastropoda	14.6	2.2	40.0	8.7	13.3	11.1	28.6	22.2
Trichoptera larvae	4.9	13.3	0	6.5	6.7	5.6	0	22.2
Diptera larvae	2.4	4.5	6.7	19.5	6.7	5.6	7.1	11.1
Diptera adults	0	0	2.2	2.8	0	0	0	0
Hemiptera	12.1	6.7	2.2	4.4	13.3	0	7.1	11.1
Coleoptera larvae	2.4	0	0	2.8	0	5.6	0	0
Coleoptera adults	4.9	2.2	0	2.8	0	0	0	0
Ephemeroptera larvae	0	0	4.5	2.8	0	0	7.1	0
Crustacea	14.6	6.7	11.1	0	0	0	7.1	0
Hydracarina	2.4	0	2.2	4.4	6.7	5.6	0	0
Unidentified insect parts	0	6.7	0	4.4	0	5.6	0	0
Unidentified animal tissue	2.4	0	0	6.5	20.0	0	0	11.1
Miscellaneous	0	0	0	2.8	0	5.6	7.1	11.1
Plant material	22.0	0	2.2	2.8	13.3	22.1	0	0

TABLE 14. Diet of young (less than 35mm) *Pfrille neogaea*, based on the percent of total occurrences in specimens from French Creek Bog.

TABLE 14.

Food Item	June 1968 N=15	July 1968 N=15	August 1968 N=14	August 1970 N=15
	% Total Occurrence			
Trichoptera larvae	2.3	4.8	0	0
Diptera larvae	25.6	19.0	22.6	6.7
Diptera adults	11.6	10.5	4.5	20.0
Hemiptera	0	4.8	9.0	33.0
Coleoptera larvae	0	14.2	31.4	0
Coleoptera adults	0	0	0	20.0
Ephemeroptera larvae	0	4.8	0	0
Collembola	7.0	0	0	6.7
Cladocera	21.0	0	0	0
Copepoda	9.3	0	0	0
Ostracoda	7.0	0	0	0
Hydracarina	7.0	19.0	4.5	0
Unidentified animal tissue	4.6	10.5	18.2	13.3
Plant material	0	4.8	9.0	0

were found in only one fish collected from May through September. The other food organisms were found at rather uniform levels in all the collections.

Animals of the phylum Mollusca were the major food organisms of adult fish throughout the sampling period. Fingernail clams (Sphaeriidae), or snails, (Gastropoda) or both were always found in at least 30% of the stomachs examined. The sharp, heavy pharyngeal teeth of P. neogaea evidently allow them to exploit this food source. The thick shells of the mollusks were usually found in small fragments inside the intestine. Trichoptera larvae, Diptera larvae, and aquatic Hemiptera (mostly Corixidae) were consistently found in the diet. Animals occurring less frequently included Diptera adults, Coleoptera larvae and adults, Ephemeroptera larvae, and Hydracarina.

Plant material, which contributed about 22% of the intestinal contents in some collections, was in the form of undigested filamentous Chlorophyta. This material was most likely ingested incidental to other food items, and probably did not contribute much food value to the fish. Many of the digestive tracts contained sand and mud, indicating that the dace did occasionally swallow non-digestible material together with the food organisms.

Miscellaneous food items included spiders, ants, small Odonata and fish eggs. The eggs completely filled the digestive tracts of a male collected June 28, 1970, and a female taken June 14, 1968. This was the time of year when *C. eos* was actively spawning in the ponds, but all breeding activity had already ceased for *P. neogaea*.

The food items selected by young fish (less than 35mm) differed noticeably from those eaten by the adults. No mollusks at all were found in any of these fish (Table 14). This could be related to the size of the pharyngeal teeth. Diptera larvae and adults were the food organisms found most consistently in the fish during their first months of life.

Small crustaceans (Cladocera, Ostracoda, Copepoda) were found in the alimentary tracts of the two month old fish collected in June. These animals apparently were important food items during the early feeding stages of the fry, but were not included in any stomachs examined after June. Aquatic Hemiptera formed an increasing percentage of the diet after June, as did Coleoptera larvae and adults in some of the collections.

Feeding Behavior

The adult fish feed on relatively large, hard organisms associated with the bottom of the pond or some other substrate such as vegetation. Feeding experiments in aquaria indicated that adult fish could easily consume entire last instar larvae of the mealworm beetle, *Tenebrio molitor*. The food items found in the larger dace did not include many actively swimming organisms. Many small fish of suitable eating size were present in the pond at all times, but none were found in the specimens examined.

Small crustaceans were an important food source to recently hatched dace, but the fish seemed to prefer larger organisms as they grew. Schools of young fish swam near the surface of the pond in shallow water, feeding on more actively swimming forms than the adults ate.

The results of the food survey could have been influenced by the collecting procedures. If adult fish swam into a minnow trap and could not escape, they could eat only the food items available inside the trap. Observations discount this occurrence, since fish were seen swimming in and out of the minnow traps at will. A more likely possibility is that the traps selectively attracted mollusk-eating fish, since these devices often accumulated considerable numbers of snails. In any case, the mollusks are an important source of food to at least many of the finescale dace present. The fish smaller than 35mm were collected by sudden sweeps of the dip net, so they were taken in a nearly random fashion.

The digestion rates of various food organisms has been shown to influence food studies (Hunt, 1960; Keast and Welsh, 1968; Seaburg and Moyle, 1964; Windell, 1968). There is a definite possibility that many soft-bodied organisms were not properly represented in the diet because they were digested at a faster rate than the mollusks and arthropods.

ECOLOGICAL CONSIDERATIONS

Sympatric Species

Five species of fish were present in the beaver ponds at French Creek Bog. All of these fishes were common and were regularly collected in the minnow traps. Cyprinids in addition to Pfrille neogaea included the northern redbelly dace, Chrosomus eos, and the fathead minnow, Pimephales promelas; also present were the mud minnow, Umbra limi (Umbridae) and the brook stickleback, Culea inconstans (Gasterosteidae).

All of these fish species are well suited to the swampy nature of the habitat. Hubbs and Cooper (1936: 8-9) stated that in Michigan, C. eos and P. promelas were often restricted to small ponds where there was little competition with other species of fishes. They also found that the bog-like lakes, beaver ponds, and small weedy, "muskeg" streams of northern Michigan frequently contained an association of minnows including all or most of the following: northern dace, Margariscus margarita; finescale dace, P. neogaea; northern redbelly dace, C. eos; brassy minnow, Hybognathus hankinsoni; and fathead minnow, P. promelas. The three minnow species found in the French Creek beaver ponds are thus known to live together successfully in such a habitat.

The chief competitor of P. neogaea with respect to food is Umbra limi, which possess large terminal mouths, strong jaws, and attain a length of about 120mm. It would appear that mudminnows eat the same organisms as finescale dace, but apparently their feeding methods are different. Umbra is a very slow swimmer, and lies concealed in mud or vegetation much of the time; the prey is attacked with a sudden rush (Keast and Webb, 1966: 1851). My observations indicate that finescale dace are stronger swimmers and that they often feed by patrolling an area in schools.

Hybridization

It is a well known-known fact that the hybridization of Pfrille neogaea with Chrosomus eos commonly occurs in many areas (Greeley, 1934; Greeley and Bishop, 1932, 1933; Gilbert, 1962:183; Taylor, 1954:42). No other single aspect of this dace's biology has received as much attention. The hybrids have been reported from New York, Michigan, Ontario, Quebec, South Dakota, and Minnesota. P. neogaea x C. eos hybrids have been collected in Colorado (Bailey and Allum, 1962:40) and Montana (Brown, 1971:86), but no specimens of pure P. neogaea have been taken in those states. Greeley and Greene (1931:86) stated that in many locations of New York, hybrids were more numerous than either of the parent species.

Although hybrids of Pfrille and Chrosomus are common in many localities, they are by no means the rule in all. Greene (1935:85-87) examined 18 collections of P. neogaea from Wisconsin; although 15 of these also contained C. eos, not even one of the 857 specimens was identified as a hybrid. New (1962:151) reported collecting large numbers of both species from Line Pond, New York, but he stated that no hybrids have ever been identified from that locality. Hybrids in Minnesota have been restricted to four eastern localities. The Arrowhead (Brule) and Cascade rivers empty into Lake Superior, and Pickerel Lake Bog lies near these streams; Wilbur Brook drains a boggy area into the St. Croix River (see Figure 2 for the map locations, and Appendix Tables B and C for the collection data). Phillips (1968:111-116) provided morphological data for the Arrowhead and Cascade River collections; Table 15 summarizes some comparative data on the specimens captured in Wilbur Brook and Pickeral Lake Bog.

Hubbs and Brown (1929:28) found the hybrids to be intermediate in all the essential morphological features distinguishing the two species. The data from Table 15 demonstrates the intermediate nature of the Minnesota hybrids with respect to the ratios of the head length, width, and depth to the standard length, and with respect to the ratios upper jaw/standard length, snout length/upper jaw length, and width of gape/standard length. The best external characteristic for distinguishing among the parental species and the hybrid (Plate 9) would be the ratio snout length/upper jaw length. The value of this ratio for Pfrille is always

TABLE 15. Comparison of six selected body proportions of *Pfrille neogaea*, *C. eos*, and *P. neogaea* x *C. eos* hybrids taken from Wilbur Brook, Pine Co. Minnesota, May 24, 1970.

TABLE 15.

Character	*P. neogaea*			*P. neogaea* x *C. eos*			*C. eos*		
	N	Mean	Std. error	N	Mean	Std. error	N	Mean	Std. error
Head length / Standard length	2	0.2841	.0059	5	0.2646	.0014	2	0.2520	.0020
Head width / Standard length	2	0.1764	.0138	5	0.1637	.0062	2	0.1454	.0050
Head depth / Standard length	2	0.1861	.0024	5	0.1715	.0014	2	0.1718	.0020
Upper jaw length / Standard length	2	0.0837	.0033	5	0.0772	.0014	2	0.0656	.0030
Width of gape / Standard length	2	0.0845	.0041	5	0.0723	.0040	2	0.0480	.0030
Snout length / Upper jaw length	2	0.8817	.0032	5	0.989	.0030	2	1.102	.0033

PLATE 9. Comparison of *Pfrille neogaea* with *Chrosomus eos* and *P. neogaea* x *C. eos* hybrid. Female specimens obtained from Wilbur Brook, Pine Co. Minnesota, May 24, 1970. Standard lengths range between 63-65 mm.

A. *Pfrille neogaea*

B. *P. neogaea* x *C. eos* hybrid

C. *Chrosomus eos*

less than one (Table 4), always consistently greater than one for C. eos (Phillips, 1969a:507), and near unity for the hybrids (Table 15).

Two internal characters were also intermediate in the hybrids. The normal pharyngeal tooth formula for Chrosomus is 0,5-5,0 (Eastman, 1970); Pfrille is normally 2,5-4,2. The hybrids demonstrated the intermediate formulas 1,5-5,1 or 1,4-4,1 (Figure 13). The ratio intestine length/standard length is nearly always less than one in Pfrille (rarely equal to one in very large specimens; see Table 5 and Figure 5); in Chrosomus the value is usually greater than 1.5, while in the hybrids it is between 1.0 and 1.5 (Phillips, 1968:117).

Both Hubbs (1955:10) and New (1962:151) reported that male hybrids of P. neogaea x C. eos were essentially non-existent; all of the Minnesota specimens I have examined were also females. The three live hybrids taken from Wilbur Brook had bright red coloration on their lower sides, very similar to that already described for some of the male P. neogaea (Plate 2C). This was interesting, since none of the female P. neogaea or C. eos collected from the Itasca Park region demonstrated any trace of red coloration. All the other external features of the hybrids were characteristic of female specimens. Upon dissection, the hybrids (all collected in late May) revealed large ovaries with well-developed eggs.

FIGURE 13. Comparison of the pharyngeal arches of *Pfrille neogaea*, *Chrosomus eos*, and *P. neogaea* x *C. eos* hybrids.

Although indicated by circumstantial evidence, the fertility of the hybrids has never been completely proven. The statistical analysis of New (1962) indicated that the hybrids tended to be intermediate in some characteristics, but more similar to one of the parental species in others. Since F_1 hybrids are usually intermediate, New suspected that introgression was occurring. Phillips (1968:114-116) cited evidence that backcrossing of F_1 hybrids to C. eos occurred in two hybrid collections taken in northeastern Minnesota. Legendre (1970) claimed to have located self-propagating populations comprised entirely of P. neogaea x C. eos hybrids in certain lakes in Quebec. He used this information as evidence pointing to the fertility of the hybrids.

The best way to experiment with the fertility of the hybrids is in the laboratory. Crosses should be made of Pfrille with Chrosomus to obtain individuals known to be hybrids, then these animals could be crossed with either of the parent species to test their fertility under controlled conditions. The morphological traits of the fish of known pedigree could be compared with those taken from the field. To my knowledge, no experimental crosses between Pfrille and Chrosomus have been attempted.

From the evidence to date, I find it difficult to accept the fact that a population could be entirely composed of P. neogaea x C. eos hybrids. Since all the known examples of these hybrids are females, how could they reproduce without males of the parental species? Legendre (1970) made no mention of male fish in his hybrid populations. If males were present, the description of their morphology, breeding behavior, and coloration would prove to be very interesting indeed.

The answer to this dilemma might be found in Legendre's (1970:1175) definition of a hybrid population. He stated "....the fish of the various collections were considered to be hybrids if some of their metric characters showed a significant variation from one parent species to the other, and if at least some specimens deviated in important non-metric characteristics from the most closely related species." Data from the French Creek Bog collections of P. neogaea, which contained no hybrids, demonstrated that many metric characters could vary significantly within the same population if no allowance was made for differences in sex and size of the specimens (see Tables 2, 3, and 4). Legendre gave no data on the composition of his collections with respect to sex and size. Certainly, any collection of P. neogaea which included a number of hybrid specimens would be expected to fulfill Legendre's definition; it is not so certain that all the specimens are therefore hybrids.

I prefer to think of Legendre's lakes as representing mixed populations of P. neogaea, C. eos, and their hybrids. The parental species would not have to be very common; Hubbs (1955:2) described a sunfish population comprised of 95% hybrids.

At least one factor resulting in reproductive isolation between P. neogaea and C. eos has been observed in French Creek Bog. This is a separation of the spawning seasons for the species. Pfrille was observed spawning in late April and early May in three consecutive years; no breeding specimens were taken as late as June. During the same years, C. eos did not begin to spawn until early June. Male specimens of C. eos collected during the spawning season of P. neogaea were not highly colored; the ovaries of C. eos females contained immature eggs.

Most likely the breeding behavior of Pfrille and C. eos is similar enough to allow inter-specific spawning in localities where the breeding seasons overlap.

Predators

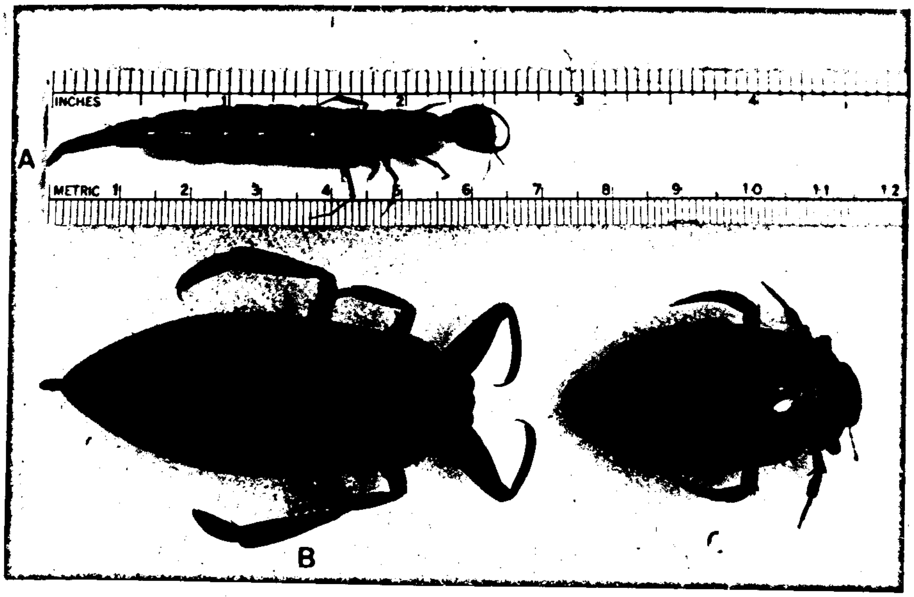
During the field work associated with this study, several predators of Pfrille neogaea were observed. The chief predators of Pfrille in French Creek Bog were undoubtedly insects. At least three species of large predacious diving beetles of the genus Dytiscus, both larvae and adults, were frequently found devouring the fish contained in the minnow traps. Just as deadly to the dace was the giant water bug, Lethocerus americanus. All three of these common insect predators were as large as the average adult fish collected (Plate 10). Smaller carnivorous insects, such as back swimmers (Notonectidae),

PLATE 10. Insect predators of *Pfrille neogaea*.

A. *Dytiscus* sp. larva

B. *Lethocerus americanus* adult

C. *Dytiscus* sp. adult


INCHES
METRIC
A
B

very likely consume considerable numbers of the young minnows.

Although no large predatory fish were present in French Creek Bog, brook trout (Salvelinus fontinalis) and northern pike (Esox lucius) are commonly found in the same streams and ponds as Pfrille. The mud minnow (Umbra limi) may feed on small finescale dace to some extent. On two occasions, pharyngeal teeth with the 2,5-4,2 formula were found in the stomachs of Umbra; since Pfrille is the only minnow in the pond with that formula, the evidence is unmistakable.

The great blue heron (Ardea herodias) and the belted kingfisher (Megaceryle alcyon) were often seen actively feeding in the beaver ponds. Although the blue heron could have been feeding on frogs as well, it probably ate at least a few fish. On one occasion a belted kingfisher was observed eating six large minnows in a ten minute period. I was watching with binoculars as the bird would circle for a few seconds over the water, dive into a school of minnows, and then swallow the fish after landing in a nearby tree. On the basis of parasites found in the fish, various grebes (Colymbiformes) should be included as predators. These birds were never observed at French Creek Bog during the study, but they are common in the area. Loons (Gavia) were likewise never seen in the study area, but are known to eat large quantities of fish from similar habitats.

Parasites

Hoffman (1970:350) listed the following parasites for *Pfrille neogaea*. Protozoa: *Myxosoma parellipticoides*, *M. pfrille*, and *Thelohanellus notatus*; Trematoda: *Uvulifer ambloplitis* and *Echiochamus donaldsoni* (the last two were found as larvae).

The metacercarial cysts of *U. ambloplitis* (often called neascus) were found to be very common on the sticklebacks, mud minnows, and fathead minnows of French Creek Bog, but they were only rarely encountered on either finescale dace or northern redbelly dace. Fewer than 1% of the specimens of *Pfrille* examined contained evidence of this parasite. Phillips (1968:172) found that the incidence of neascus in *C. erythrogaster* was also very low compared to sympatric species. Phillips concluded that the different degrees of infestation were primarily due to microhabitat selection; fish swimming in mid-water were not as likely to come in contact with the cercariae as those that were on the bottom. This may well apply to the situation at French Creek Bog.

The metacercariae of *E. donaldsoni* are normally found on the gills of fish; the definitive host is the pie-billed grebe, *Podilymbus podiceps* (Beaver, 1941). Although these have been reported as occurring on *Pfrille*, none were found on the specimens I examined from the Itasca Park region.

The metacercariae of a closely related (Echinostomatidae) trematode were found to infest a majority of the Pfrille taken at French Creek Bog. These cysts were usually located in the liver, but they were also often found in the outer wall of the gonads. More than 50 cysts were frequently taken from a single specimen. I have tentatively identified these flukes as belonging to the genus Petasiger Dietz (Schell, 1970:184). Beaver (1939) found that Petasiger nitidus Linton infected many fish in Douglas Lake, Michigan. Included in his list of intermediate hosts were Umbra limi, Notropis hudsonius, and a "number of undetermined minnows." The fish normally acquired the cercariae by eating infected snails (especially Helisoma antrosum). Beaver reported that the metacercariae were most often encysted in the pharynx and esophagus of the fish. The natural definitive host was thought to be the horned grebe, Colymbus auritus. Since it has already been established that snails provide an important food source for Pfrille in French Creek Bog, it would certainly be possible for the dace to become infected with this worm.

Bangham and Venard (1946:39) recorded the presence of immature nematodes (Agamonema) from finescale dace taken in Algonquin Park, Ontario. These worms were not observed during the present study.

SUMMARY

1. A distributional, morphological, and ecological study of the finescale dace, *Pfrille neogaea* (Cope), was conducted at the University of Minnesota from June, 1967 through May, 1971.

2. The finescale dace was found to have a confusing background of scientific nomenclature. Although recent authors have included it in the genera *Phoxinus* Raf. and *Chrosomus* Raf., these changes have not been published with supporting evidence. The finescale dace also appears to be closely related to *Semotilus margarita* (Cope) and *Couesius plumbeus* (Agassiz). In the absence of a published revision, the affinity of all these groups is considered uncertain; it is therefore felt (following McPhail and Lindsey, 1970) that the finescale dace is best retained as *Pfrille neogaea* (Cope) Jordan, 1924.

3. The distribution of *Pfrille* in Minnesota was found to include the Red River, Arctic, Mississippi, and Superior drainage basins. The presence of *Pfrille* in the St. Croix River drainage was established. This population, together with those recorded from the upper Mississippi River, indicates that the postglacial dispersal of the finescale dace included both the Missouri and upper Mississippi systems.

4. The morphological and ecological aspects of this study were conducted on a population of dace found in French Creek Bog, Itasca State Park. The fish, collected primarily with minnow traps, were taken from beaver ponds located less than one half mile from the headwaters of the Mississippi River in Clearwater County.

5. Males collected during the breeding season displayed three distinct color phases: yellow, red, and both yellow and red. Breeding females often developed yellow coloration on their lower sides, but no individuals with red pigmentation were observed.

6. The ratios of all the fin lengths to standard length were significantly larger in male specimens than they were in females. The pectoral fins of the males were highly modified, especially during the breeding season. The ratios of the tail length and caudal peduncle depth to standard length were also significantly larger in males.

7. The breeding tubercles of the males were of two types. Those located anterior to the pectoral fins were arranged in regular rows in a triangular pattern; those found at the base of the anal fin were formed by distinct papillae, one per scale. These pearl organs persisted only during April and May. None were found on females.

8. The ratios of five selected head proportions were found to vary with the size of the specimens. The snout and upper jaw lengths increased faster than the standard length; the orbit length increased at a slower rate than did the standard length. The ratios snout to orbit length and snout to upper jaw length increased with an increase in total specimen length. The intestine length was also found to increase at a faster rate than did the total length. Despite this allometric growth, the ratios of the snout to upper jaw and the intestine to standard length were found to be of taxonomic value since they were always less than one. These values are considerably more than one in the genus Chrosomus.

9. The proportional body depths did not vary between sexes, but did vary seasonally.

10. The breeding behavior of Pfrille in French Creek Bog and in aquaria was described. Females suddenly left a school and were chased under debris by several males. Spawning lasted only a few seconds, after which the fish rejoined the school.

11. Cyclic changes in the gonosomatic index of both males and females indicated that only a single breeding period, in late April and early May, occurred each year.

12. The fecundity of Pfrille was found to increase linearly with the standard length. The maximum number

of eggs contained in a large female just prior to spawning was 3,060.

13. Males averaged slightly larger than females after one year's growth, but females became significantly larger than the males after age three.

14. The major food items of adult dace in French Creek were fingernail clams and snails, followed by various aquatic insects. Young dace depended primarily on insect larvae. Plant material occurred in up to 20% of the fish in some collections, but did not appear to be digested.

15. Hybrids of Pfrille neogaea with Chrosomus eos have been taken from four locations in eastern Minnesota. The live hybrids collected in May, which were unusual in bearing bright red pigmentation on their sides, bore well-developed eggs. In French Creek Bog, where no hybrids were found, Pfrille finished spawning prior to the onset of the breeding of C. eos.

16. The main predators of Pfrille at French Creek Bog included the insects Dytiscus sp. and Lethocerus americanus. Herons, kingfishers, grebes, and loons, together with northern pike and brook trout, constitute the potential vertebrate predators.

17. Although only rarely infected with neascus, a majority of the dace examined possessed metacercariae that were tentatively identified as Petasiger Dietz. These parasites were found in the liver and gonads.

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APPENDIX

Table A. Arctic Drainage

Museum Number	N	Locality	Date	Collector
19043	2	Beltrami Co. Waskish Pond #2	9/ 8/41	Minn Cons Dept
18880	2	Beltrami Co. Medicine Lake, T149,R32,S10,15	9/ 6/58	Minn Cons Dept
17975	1	Beltrami Co. Moose R. 10 mi. N., 5 mi. E. of Grygla	6/27/55	Tasker
17977	5	Marshall Co. Mud R. .2 mi. below Grygla	6/27/55	Tasker
18132	1	Same as above, but mislabeled <u>C. eos</u>		
18131 18133	47 1	Marshall Co. small pools below dam at Agassiz Wildlife Refuge (all young fish misidentified as <u>C. eos</u>)	6/27/55	Tasker
18129	6	Lake of the Woods Co. North Fork R. 30 mi. S. of Warroad (all misidentified as <u>C. eos</u>)		
18128	25	Lake of the Woods Co. Clear R. 20 mi. S.W. of Roosevelt (all young fish misidentified as <u>C. eos</u>)	6/27/55	Tasker
17963	4	Roseau Co. Warroad R.	6/26/55	Tasker
63-006	1	Clearwater Co. Hier (Mud) Ck. T144,R37	7/ 5/63	Underhill

Table A. Arctic Drainage (Concluded)

Museum Number	N	Locality	Date	Collector
-	1	Wilkin Co. Lawndale Ck.	1961	Minn Cons Dept
19629	6	Lake Co. Camdre Lake, T62,R9,S7	1962	Minn Cons Dept
19700	6	Lake Co. Maniwaki Lake, T62,R7,S3		Minn Cons Dept
19605	12	Lake Co. Gypsy Lake T60,R10,S6	10/11/61	Minn Cons Dept
19584	2	Lake Co. Finn Pond, T60,R8,S22	10/11/61	Minn Cons Dept
19313	5	Lake Co. Kawishiwi R. headwaters	1961	Dave Etnier
-	28	Lake Co. Kawishiwi R.	1968	Minn Cons Dept
-	10	Lake Co. Lena Lake T60,R8,55	1964	Minn Cons Dept

Table B. Lake Superior Drainage

Museum Number	N	Locality	Date	Collector
1149	1	St. Louis Co. Beaver L.	9/ 6/40	J. B. Moyle
11452	2	St. Louis Co. Lester R. near mouth	4/ 2/40	J. B. Moyle
11448	2	St. Louis Co. Lester R.	8/21/40	J. B. Moyle
11520	1	St. Louis Co. Lester R. mouth (misidentified as *C. eos*)		
11736	3	St. Louis Co. lake near Finland	12/ 1/40	Eckbeck Forest Ranger
14863	3	St. Louis Co. French R. T52,R13,S28	8/27/46	Minn Cons Dept
11451	1	Lake Co. Gooseberry R.	7/ 6/40	J. B. Moyle
19114	1	Lake Co. Split Rock R. (labeled *C. eos*)	7/ 9/55	Minn Cons Dept
14104	2	Lake Co. Rock Ck. (misidentified as *C. eos*)	7/12/40	J. B. Moyle
13308	2	Lake Co. Two Island R.	6/26/41	J. B. Moyle
10601	2	Cook Co. Brule L.	7/ 9/35	-
13289	1	Cook Co. Cascade R. (2 *C. eos* x *P. neogaea*)	9/ 9/41	M. B. Moyle
19310	1	Cook Co. Arrowhead Creek	1961	Dave Etnier

Table B. Lake Superior Drainage (Continued)

Museum Number	N	Locality	Date	Collector
13375	11	Cook Co. Kadunce Ck.	9/15/41	J. B. Moyle
12091	3	Cook Co. Arrowhead R. (this collection was misidentified as *C. eos*; it contained many *C. eos* x *P. neogaea* hybrids	8/21/41	J. B. Moyle
12189	1	Cook Co. Devil's Track R.	8/19/41	J. B. Moyle
-	30	Cook Co. Pickerel Lake Bog Pond (2 *C. eos* x *P. neogaea* hybrids)	5/23/71	Stan Smith
13203	1	Carlton Co. Otter Ck. T48,R17,S29	8/ 1/41	-

Table C. Mississippi River Drainage

Museum Number	N	Locality	Date	Collector
18147	1	Clearwater Co. Mississippi R. (misidentified in C. eos collection)	7/14/54	S. Eddy
19293	1	Clearwater Co. Mississippi R. at Hwy 92	6/22/60	J. Ernest
19758	3	Clearwater Co. Mississippi R. headwaters	6/22/64	J. Underhill
-	4	Clearwater Co. Mississippi R. headwaters	1966-1969	J. Underhill
-	2	Clearwater Co. Sucker Bk.	6/25/65	J. Underhill
-	1	Clearwater Co. Long Lake	6/16/65	J. Underhill
-	650	Clearwater Co. French Creek Bog	1967-1971	R. Stasiak
-	51	Clearwater Co. Clarke L., Myrtle L.	6/29/71	Stan Smith
19042	3	Anoka Co. Outlet to Deer Lake, T33,R23,S15	3/22/42	Fish Prop
-	1	Pine Co. Wilbur Bk. at Hwy 48 (several neogaea x eos hybrids also)	5/24/70	R. Stasiak